SEASONAL MOVEMENT PATTERNS AND HABITAT OCCUPANCY OF

KOTZEBUE REGION INCONNU

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A

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## Abstract

Inconnu *Stenodus leucichthys* are large, long-lived piscivorous whitefish harvested in subsistence and sport fisheries in Alaska. My study was conducted to describe the seasonal movements and habitat occupancy of inconnu in the Selawik and Kobuk River drainages, Alaska, from 2010 through 2012. Methods consisted of surgically implanting acoustic telemetry tags in 80 fish from both rivers in 2010 and 2011 (n = 320), and deploying a fixed array of 20 Vemco VR2W acoustic receiving stations affixed with archival tags throughout Selawik Lake and Hotham Inlet. Tagged inconnu detections revealed that Selawik and Kobuk River inconnu displayed a high degree of spatial and temporal overlap while co-located in the Hotham Inlet/Selawik Lake complex. During the winter period, tagged fish predominately occupied the northern end of Hotham Inlet. In the summer period, fish transitioned from the northern end of Hotham Inlet to Selawik Lake and also the southern end of Hotham Inlet. Average daily displacements for Selawik and Kobuk River inconnu ranged from 2,000 to 10,000 m/day. Water temperature and salinity occupancy ranged from -1.39 to 18.69ºC and 0 to 31.3 psu, respectively. No stock-specific or temporal trends in temperature and salinity occupancy by inconnu from the Selawik and Kobuk rivers were detected during my study. In addition to providing a more complete account of the life history of inconnu, these results will aid managers in developing future management strategies.

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**Introduction**

The inconnu *Stenodus leucichthys* (locally known as sheefish) is the largest whitefish species in the family Salmonidae, subfamily Coregoninae. Having a holarctic distribution, inconnu are found in the Arctic and subarctic waters of North America, Asia, and the Caspian Sea (Alt 1969; McPhail and Lindsey 1970; Scott and Crossman 1973). In Alaska, the primary stocks are found in the Kuskokwim, Yukon, Kobuk, and Selawik River drainages as amphidromous and potamodromous populations (Alt 1987, 1988). The life-history characteristics of Alaskan inconnu are generally well understood (Alt 1969, 1973, 1987). For example, potamodromous inconnu of the Kuskokwim River and Minto Flats area are the fastest growing populations, reaching 80 cm by age 10 (Alt 1987). Kobuk and Selawik River inconnu are the slowest growing stocks, but reach the largest size (up to 27 kg) and also live the longest (up to age 21; Alt 1988). Age at maturity generally ranges from 4 to 7 for males and 6 to 14 for females, with Kobuk and Selawik River inconnu having the oldest ages at maturity (7 to 9 years for males and 9 to 12 years for females; Alt 1988). Inconnu are iteroparous and are thought to spawn every 2 to 4 years; however, sequential year spawning has been documented (Scott and Crossman 1973; Savereide 2010). Amphidromous inconnu undertake long migrations to reach their freshwater spawning grounds; for example, Yukon River inconnu travel approximately 1,700 km up river to spawn (Brown 2000). Adult inconnu are piscivorous and have a diet consisting of Arctic lamprey *Lethenteron camtschaticum*, whitefishes *Coregonus* spp., northern pike *Esox lucius*, longnose suckers *Catostomus catostomus*, and young Pacific salmon *Oncorhynchus* spp. (Alt 1987, 1988).

In the Kotzebue region, inconnu live their entire life cycle within the Selawik, Noatak, and Kobuk rivers, Selawik Lake (freshwater), and Hotham Inlet (brackish water with a gradient of higher salinity towards Kotzebue Sound; Underwood 2000). Historically identified as a single stock (Alt 1969, 1977), genetic analysis (Miller et al. 1998) and tag-return studies (Taube and Wuttig 1998; Underwood 2000) have identified that Kobuk and Selawik River inconnu constitute separate and distinct spawning stocks and exhibit spawning site fidelity (Underwood 2000; Savereide 2010). Radio telemetry and conventional tag recaptures indicate that with ice break-up in spring, mature inconnu begin a slow migration upstream to spawning areas in the Selawik and Kobuk rivers (Alt 1977; Underwood et al. 1998; Savereide 2010). Underwood (2000) concluded that precipitation events triggered these upstream movements for inconnu in the Selawik River. While the maturing inconnu are migrating to the spawning areas, adult non-spawning and immature inconnu remain in summer feeding areas of Hotham Inlet, Selawik Lake, and the lower reaches of Kobuk and Selawik rivers (Alt 1969, 1977). As determined by radio telemetry, spawning-phase inconnu reach spawning areas, which consist of a 12-km and 128-km reach in the upper Selawik and Kobuk rivers, respectively, by early September (Alt 1969; Taube and Wuttig 1998; Underwood et al. 1998; Hander et al. 2008; Savereide 2010). These spawning areas are approximately 200 km and 550 km upstream from the mouths of the Selawik and Kobuk rivers, respectively.

Inconnu are surface broadcast spawners and spawning occurs from late September through early October (Alt 1988). Spawning activities occur at night over gravel and cobble substrates when water temperatures range from 1.4 to 4.6°C (Alt 1969; Morrow

1980). Fertilized eggs settle into interstitial spaces in the substrate where they develop throughout winter (Alt 1969). Following spawning, inconnu rapidly migrate downstream from the Selawik and Kobuk rivers to overwintering areas in Selawik Lake and Hotham Inlet (Underwood 2000; Savereide 2010). Inconnu have been captured during winter subsistence fisheries throughout Hotham Inlet and associated waterways (Alt 1987; Taube 1996, 1997; Taube and Wuttig 1998; Underwood et al. 1998; Underwood 2000), but knowledge on their distribution and habitat characteristics during this period are unknown. This lack of information is due to sampling constraints associated with radio telemetry in saline waters. Although radio telemetry has been used to track the spawning movements of inconnu in the Selawik and Kobuk rivers (Underwood et al. 1998; Hander et al. 2008; Savereide 2010), the attenuation of radio waves in high conductivity waters, such as Hotham Inlet, makes tracking fish with this type of telemetry equipment impossible unless the fish periodically surfaces (McCleave et al. 1978). However, the development of low-cost, automated submersible acoustic receivers that can be deployed at key locations across geographic areas has enabled the detection of large numbers of coded acoustic tags that when attached to fish, allows for the detection of them in freshwater, brackish, and marine waters (Voegeli et al. 1998; Comeau et al. 2002; Welch et al. 2002; Nielsen et al. 2011).

To gain a better understanding of Kotzebue region inconnu population dynamics, the Alaska Department of Fish and Game (ADF&G) conducted aerial counts of spawning inconnu in the Kobuk River from 1966 to 1971, which ranged from 1,025 to 8,166 fish (Alt 1987). Sporadic aerial counts were conducted in 1979, 1980, 1984, 1991, and 1992, and ranged from 1,772 to 17,335 spawning fish (Lean et al. 1996). Aerial counts were also conducted on the Selawik River in 1968 and 1971, and the spawning population size was estimated to be 1,243 and 1,105 fish, respectively (Alt 1987). Due to known shortcomings associated with aerial surveys, ground-based inconnu population studies were initiated in the Kobuk River by ADF&G (Taube 1996, 1997; Taube and Wuttig 1998) and in the Selawik River by the U.S. Fish and Wildlife Service (USFWS) in 1993 (Underwood et al. 1998). Spawning abundance estimates for the Kobuk River were 32,273 (95% CI = 22,554–41,992), 40,036 (90% CI = 25,241–60,831), and 32,511(90% CI = 24,480–40,542) fish in 1995, 1996, and 1997, respectively (Taube 1996, 1997; Taube and Wuttig 1998). Selawik River spawning abundances were 5,190 (95% CI = 3,690–7,272) and 5,157 (95% CI = 3,038–12,983) fish in 1995 and 1996, respectively (Underwood et al. 1998). Hander et al. (2008) revisited Selawik River spawning areas in 2004 and 2005 and estimated the spawning abundance of inconnu to be 23,652 (95% CI = 13,383–33,920) and 46,324 (95% CI = 25,069–67,580) fish, respectively.

In the Kotzebue region of northwest Alaska, inconnu provide a valuable subsistence, commercial, and recreational resource. It is estimated that up to 20,000 inconnu are harvested annually in the Kotzebue region, primarily in the Kobuk and Selawik rivers, Hotham Inlet, and Selawik Lake (Georgette and Loon 1990; Lean et al. 1992; Taube 1997; Savereide 2002; Georgette and Koster 2005; Georgette and Shiedt 2005). Inconnu are also harvested in this region from the Noatak and Buckland rivers (Alt 1987). In terms of magnitude, commercial and sport fishery harvest is much lower than subsistence harvest (Scanlon 2008). Savereide (2002) reported that in 1997, the subsistence harvest of inconnu was 23,509 fish, while the sport and commercial harvest of inconnu was 902 and zero fish, respectively. Inconnu captured for subsistence purposes are used year round for human and canine consumption (Alt 1969, 1987). From 2002–2004, 79% of Kotzebue households reported that inconnu were harvested for subsistence purposes. The total number of inconnu harvested annually by Kotzebue residents ranged from 7,747 to 27,077 fish (Whiting 2006). Subsistence inconnu harvest from 1995–1999 in five Kobuk River villages and Noatak River ranged from 5,350 (1998) to 9,805 (1997) fish (Georgette and Koster 2005). The winter subsistence gill-net harvest of inconnu in Hotham Inlet in 2000–2001 was 14,533 fish (Savereide 2002), which was similar to estimates of 15,161 fish (95% CI = 11,925–18,396) in 1995–1996 and 13,704 fish (95% CI = 9,880–17,528) in 1996–1997 for this area (Taube and Wuttig 1998). The largest annual subsistence harvest for inconnu in the Kotzebue region was 31,293 fish and occurred in 1967–1968 (Brennan et al. 1998).

Subsistence harvest in the Kotzebue region occurs in four distinct phases that span the entire year. The first phase occurs during the summer when inconnu are caught with gill nets on their upstream spawning migration. During the second phase in the fall, beach seines are used to capture inconnu at spawning areas. The third and fourth phases occur during the winter in the form of mixed-stock under-ice gill netting (early winter) and angling (late winter) throughout Hotham Inlet, and these phases comprise the largest proportion of documented harvest in the region (Savereide 2002). Although inconnu in the Kotzebue region are a culturally importance subsistence resource harvested in a mixed-stock fishery, there are currently no science-based, stock-specific harvest guidelines for the mixed-stock winter fishery, which has led to concerns for the possible overharvest of the less abundant Selawik River stock (Lean et al. 1992; Miller et al. 1998; Kohler et al. 2005). For the establishment of well-founded stock-specific winter harvest guidelines, knowledge on the movements and distribution of inconnu within potential wintering areas must be obtained (Savereide 2002). Further, abiotic habitat variables such as water temperature and salinity can play a critical role in limiting the amount of usable winter habitat (Cunjak 1996; Jackson et al. 2001). Therefore, a better understanding of the distribution, movement patterns, and habitat characteristics of inconnu is necessary to make informed management decisions for this species.

Over the last century, the Arctic region warmed to its highest temperature in over 400 years (Overpeck et al. 1997). An implication associated with a warming Arctic is hydrologic regime shifts. Predicted regime shifts in Arctic lake and river systems include delayed freeze up, earlier ice break-up, higher autumn water temperature, and reduced ice thickness (Prowse et al. 2006). In addition to climate-induced habitat changes, an application for the development of an ice road between Selawik and an inholding with the Selawik National Wildlife Refuge (SNWR) boundary has been approved. The creation of ice roads requires water drawdowns, which could potentially have a negative impact on the availability and quality of winter habitats for inconnu. Examples of negative impacts include habitat fragmentation, isolation, and changes in water quality, which may lead to movement barriers (L. Ayres, USFWS SNWR, personal communication). It is believed that there will be additional demands for ice roads in this region. Based on these concerns, there is a need to better understand the habitat characteristics of inconnu in the Kotzebue region.

Several studies have examined inconnu spawning abundance, stock and genetic structure, and spawning migration patterns in the Selawik and Kobuk River drainages (Taube 1996, 1997; Miller et al. 1998; Taube and Wuttig 1998; Underwood et al. 1998; Underwood 2000; Hander et al. 2008). However, there have been no evaluations of inconnu migration and distribution relative to physico-chemical attributes within Hotham Inlet and Selawik Lake. My study examined these missing areas of inconnu ecology and documented the seasonal movement patterns and associated water temperature and salinity occupancy of inconnu in the Hotham Inlet/Selawik Lake complex. The following thesis is divided into two stand-alone chapters, each describing a different component of my study. With the current lack of overall life-history information for this species, my results will allow managers to determine the appropriateness of stock-specific harvest guidelines in the region by comparing the spatial, temporal, and habitat overlap between the two stocks. In addition to increasing our basic understanding of the life history and ecology of inconnu, my results will also aid managers in detecting possible threats to Kotzebue region inconnu from climate- or anthropogenic-induced environmental changes.

Chapter 1 describes the seasonal distribution and movements of inconnu from the Selawik and Kobuk rivers within the Hotham Inlet/Selawik Lake complex. With the lack of information on movements of inconnu not directly associated with spawning, these data will allow managers to determine the appropriateness of winter stock-specific harvest guidelines in the region by examining the degree of spatial and temporal overlap between the two stocks within the potential overwintering area. If harvest restrictions are required for Kotzebue region inconnu, my results will also allow managers to make decisions on the spatial and temporal restrictions that could be implemented.

Chapter 2 explores the seasonal water temperature and salinity occupancy of Kotzebue region inconnu within the Hotham Inlet/Selawik Lake complex. Along with providing a more complete picture of inconnu habitat characteristics, the results from this chapter provide the necessary baseline data for future comparisons to evaluate climate- and anthropogenic-induced changes in the Hotham Inlet/Selawik Lake complex. Comparisons of my results to future habitat collections will allow researchers to determine any human- or climate-induced changes in the region. Also, by determining the habitat occupancy of inconnu, my results can be used to identify risks to habitat availability due to the construction of ice roads.

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## Chapter 1: Seasonal movement patterns of inconnu in the Kotzebue Region of northwestern Alaska[1]

### Abstract

My study was conducted to describe the summer and winter distribution of inconnu *Stenodus leucichthys* in the Selawik and Kobuk River drainages, Alaska, between 2010 and 2012. Data collection methods consisted of surgically implanting acoustic telemetry tags in 80 fish from both the Selawik and Kobuk rivers in 2010 and 2011 (n = 320), and deploying a fixed array of 20 Vemco VR2W acoustic receiving stations throughout Selawik Lake and Hotham Inlet. The winter distribution of inconnu from the Selawik and Kobuk rivers were similar, with tagged fish occupying the northern end of Hotham Inlet predominately during the winter period. However, fish from both rivers were detected moving to Selawik Lake periodically throughout the winter period. The summer distribution of inconnu from both rivers was also similar. During the summer, fish transitioned from the northern end of Hotham Inlet to Selawik Lake and also the southern end of Hotham Inlet. With the exception of October 2010, average daily displacements for Selawik and Kobuk River inconnu ranged from 2,000 to 6,000 m/day. Inconnu from the Selawik and Kobuk rivers also displayed a high degree of spatial and temporal overlap during summer and winter periods within Selawik Lake and Hotham Inlet. Along with providing a more complete account of the life history of inconnu, these results will aid managers in developing future management strategies.

[1]Smith, N. J. and T. M. Sutton. 2013. Seasonal movement patterns of inconnu in the Kotzebue Region of northwestern Alaska. Prepared for submission in North American Journal of Fisheries Management.

## Introduction

Migration in freshwater fishes is considered to be a behavioral response for exploiting seasonally available resources (i.e., food, habitat, predator avoidance), which ultimately increases the fitness of individual fishes (Aidley 1981; Lucas and Baras 2001). A typical pattern for many migratory freshwater fishes is to move among spawning, feeding, and overwintering habitats in a cyclical pattern (Northcote 1978; Cunjak 1996). Undertaking seasonal migrations is especially important for temperate and Arctic fishes where seasonally harsh environmental conditions can limit the availability of food and habitat (Peterson 1982; Cunjak 1988; Craig 1989). One seasonal transition that typically requires migration is the onset of winter in the Arctic, because the quantity and quality of suitable habit is severely reduced relative to summer (Craig 1989; Reynolds 1997). In many cases, Arctic streams and shallow lakes freeze completely solid during the winter, thereby making them unusable (Craig 1989).

Fish migrations occur at varying temporal and spatial scales. At the smallest scale, fish may move vertically within their given habitat to access specific water temperatures, and, at the largest scale, migrations occur at the system level where fish move between marine and freshwater environments (Reynolds 1997). Abiotic constraints influence winter migrations and habitat selection for many fishes including, Arctic cisco *Coregonus autumnalis* and other anadromous fishes in the Sagavanirktok River delta (Schmidt et al. 1989), Arctic char *Salvelinus alpinus*, now believed to be Dolly Varden char *Salvelinus malma,* in the Canning River, Alaska (Craig 1978), and Arctic grayling *Thymallus* *arcticus* in coastal streams of the Arctic National Wildlife Refuge of Alaska (West et al. 1992).

Inconnu *Stenodus leucichthys* (sheefish) is a large, highly migratory, piscivorous whitefish (subfamily: Coregoninae) species found in the Arctic and subarctic waters of North America and Asia as well as the Caspian Sea (Alt 1969; McPhail and Lindsey 1970; Scott and Crossman 1973). In Alaska, inconnu are found in the Kuskokwim, Yukon, Kobuk and Selawik River drainages as amphidromous and riverine populations (Alt 1987, 1988). Inconnu are iteroparous and are thought to spawn every 2 to 4 years (Scott and Crossman 1973); however, sequential-year spawning has been documented (Taube 1997; Underwood 2000). Amphidromous inconnu undertake long migrations to reach their freshwater spawning grounds; for example, inconnu travel approximately 1,700 km up river to spawn in the Yukon River (Brown 2000).

The Selawik and Kobuk River drainages support important whitefish subsistence fisheries in the Kotzebue region, with the annual harvest of whitefish exceeding that of all other fishes in the region. Of the whitefishes harvested, inconnu are one of the most important food fishes in the region, with 20,000+ fish being harvested each year in subsistence, sport, and commercial fisheries (Georgette and Loon 1990; Taube 1997; Savereide 2002; Georgette and Koster 2005; Georgette and Shiedt 2005). In 1980, the U. S. Congress recognized the importance of inconnu and identified the Selawik River stock as special interest under the Alaska National Interest Lands Conservation Act (ANILCA). With this classification, Congress mandated that inconnu be maintained at their natural diversity, which includes opportunities for continued subsistence use.

Originally identified as a single stock (Alt 1969, 1987), genetic analysis (Miller et al. 1998) and tag-return studies (Taube and Wuttig 1998; Underwood 2000) have shown that inconnu from the Kobuk and Selawik rivers constitute separate and distinct spawning populations. However, it is thought that inconnu from the Selawik and Kobuk rivers overwinter within Selawik Lake and Hotham Inlet (also known as Kobuk Lake) as a mixed stock (Underwood et al. 1998). The Selawik River terminates at Selawik Lake, which drains into Hotham Inlet, while the Kobuk River drains into Hotham Inlet. In winter fisheries, inconnu have been captured throughout Hotham Inlet and associated waterways (Taube 1996, 1997; Taube and Wuttig 1998; Underwood et al. 1998; Underwood 2000), but detailed knowledge about their distribution and behavior during this period is unknown. As such, there are no science-based, stock-specific harvest guidelines for the winter fishery, which has led to concerns of the possible overharvest of the less abundant Selawik River stock (Lean et al. 1992; Miller et al. 1998; Kohler et al. 2005).

Although radio telemetry has been used to study spawning inconnu movements in the Selawik River (Underwood et al. 1998; Hander et al. 2008) and the Kobuk River (Savereide 2010), inconnu movements in Selawik Lake and the brackish waters of Hotham Inlet are unknown due to sampling constraints associated with radio telemetry. The attenuation of radio waves in waters with high conductivity (such as occurs in Hotham Inlet) is so great that radio-telemetry tracking is not possible unless the tagged fish periodically breaches the water surface (McCleave et al. 1978). However, acoustic telemetry has allowed researchers to track fish across the freshwater to marine transition

(Welch et al. 2009). Also, the development of low cost, automated submersible receivers that can be deployed at key geographic locations has enabled the monitoring of large numbers of coded acoustic tags that allows for the tracking of tagged fish across freshwater, brackish, and marine waters (Voegeli et al. 1998; Comeau et al. 2002; Welch et al. 2002).

In this study, I describe the winter and summer movement patterns and distribution of inconnu from the Selawik and Kobuk rivers and throughout Hotham Inlet and Selawik Lake using acoustic tags and automated receivers. The objective of my study was to identify the summer and winter distribution of inconnu in the Selawik and Kobuk River drainages. These data, while increasing our basic understanding of the life-history characteristics of inconnu, will provide managers with information that will aid in the development of stock-specific harvest guidelines.

## Study Area

This study was conducted in the Selawik and Kobuk River drainages of northwestern Alaska. These drainages include the Selawik River, Kobuk River, Selawik Lake, and Hotham Inlet (Figure 1.1). In addition, an area at the mouth of the Noatak River was included as a region of additional focus because inconnu have been captured at various times of the year by local Noatak River residents and this area may also provide important winter refuge for this species (Figure 1.1; Alt 1987). A portion of my study area was located within the Selawik National Wildlife Refuge (SNWR), as well as the Kobuk Valley National Park (KVNP).

The Selawik River is designated a National Wild River and originates in the Purcell Mountains, flowing 300 km east to west within a wide tundra valley to termination in Selawik Lake. The Selawik River has two major tributaries, the Kugarak River (flowing from the north) and Tagagawik River (flowing from the south). The Kobuk River originates in the Endicott Mountains, located in the Gates of the Arctic National Park and Preserve. This river flows west approximately 800 km through the KVNP and SNWR and terminates at Hotham Inlet. Selawik Lake, the third largest lake in Alaska, is approximately 42 km in length and 30 km in width, has a surface area of 1,050 $km^2$, and has depths up to 5.5 m. This lake is a freshwater system that flows west into Hotham Inlet. An arm of Kotzebue Sound, Hotham Inlet is 80 km in length, ranges from 8 to 32 km in width, and has depths up to 7 m. Hotham Inlet, a brackish-water system with a gradient of lower to higher salinity from its origin at Selawik Lake towards Kotzebue Sound, is an outlet for the Selawik and Kobuk rivers, and is bounded on the southwest by the Baldwin Peninsula. The southern part of the inlet is stratified with a deep layer of freshwater (0 ppt) above a thin saline layer (25 ppt) during periods of ice cover. Winter water temperatures within Hotham Inlet and Selawik Lake range from 0 to 2.1ºC (R. Brown, USFWS FFWFO, personal communication).

This region of Alaska has a maritime climate during ice-free periods of the year (late May to early October), and transitions to an Arctic climate during the winter months. Air temperature extremes range from approximately 34ºC in the summer to -50ºC in the winter. The annual average precipitation ranges between 38 and 51 cm (USFWS 1993).

**Methods**

*Fish capture*

In July and August 2010 and 2011, 80 inconnu were captured on their upriver spawning migration each year from both the Selawik and Kobuk rivers (320 fish total). To ensure that only adult spawning inconnu were sampled, inconnu with fork lengths (FL) ≥ 820 mm were retained for tagging (Hander et al. 2008). Sampling in the Selawik River occurred in the vicinity of Kerulu Creek (Figure 1.1), which is located approximately 25 km downstream of the documented inconnu spawning area and 200 km upstream from the mouth of the Selawik River (Hander et al. 2008). Sampling in the Kobuk River occurred from the Native Village of Kobuk to approximately 1 km downstream of the Pah River (Figure 1.1). This river reach is approximately 550 km upstream from the Kobuk River mouth, and includes known spawning areas (Alt 1987; Taube and Wuttig 1998). Past studies indicate that inconnu exhibit spawning site fidelity (Miller et al. 1998; Taube and Wuttig 1998; Underwood 2000); therefore, it was assumed that inconnu caught at the Kobuk River sampling site were from the Kobuk stock, while inconnu captured from the Selawik River sampling site were from the Selawik stock.

The sampling gear used in this study included hook-and-line angling and haul seines (Taube 1996; Taube and Wuttig 1998; Underwood et al. 1998; Underwood 2000). Hook-and-line gear consisted of a heavy spinning rod and reel with 9.07-kg test monofilament and a single barbless Krocodile spoon (Luhr Jensen, Hood River, Oregon). Based on previous research, Stuby and Taube (1998) concluded that hooking mortality of inconnu using angling gear was low (single-hook mortality = 1.6%). During my biological sampling, no incidents of hooking mortality were recorded and I assumed hooking mortality to be zero based on the behavior of fish post-capture. To capture inconnu using haul seines (3.3 m in depth and 61.5 m in length, with 25-mm bar mesh), a boat was used to deploy the seine on the inside of shallow river bends. A 16-m lead was attached to each end of the seine. Two crew members remained on the shore holding one lead, while the boat pulled the seine perpendicular to the current. To accomplish a straight deployment, the sampling crew members on shore walked the net down the shore line. Once the net was fully deployed, it was allowed to drift for approximately 300 m. After the drift, the boat was motored to shore and the two ends were brought together. The net was then pulled on shore leaving a portion in the water to hold captured inconnu until they were processed.

*Transmitter specifications*

During both sampling years, Vemco V9TP-2L-coded acoustic transmitters were surgically implanted into inconnu. The selected transmitter for this study was 9 mm in diameter and 47 mm in length, weighed 3.5 g in water, and had a 143-dB power output (Vemco, Halifax, Nova Scotia, Canada). Each tag had an expected battery life of 609 d, and would transmit at 69 kHz with a nominal delay of 180 seconds (range, 110–250 sec) between transmissions.

*Surgical methods*

At the time of capture, fish were placed in a holding tank of freshwater and were visibly examined for physical injury or signs of being stressed. Signs of stress included, but were not limited to, erratic swimming, cloudy retinas, and pale coloration resulting from retraction of blood in the extremities (Underwood et al. 1998). No fish were disqualified from my study due to physical injury or stress. Fork length (FL) was measured to the nearest 1 mm and the capture location, date and time of fish capture, capture method, time of release, and environmental conditions during the sampling period were also recorded. Prior to surgery, all surgical instruments and transmitters were disinfected with chlorhexidine and rinsed with freshwater before use, and new sterile gloves were worn for the duration of each surgical procedure.

After passing the initial physical examination, candidate inconnu were placed in a 100-L holding tub containing a clove oil (20-30 mg/L) anesthetic solution (Anderson et al. 1997; Prince and Powell 2000; Borski and Hodson 2003; Brown 2006). Inconnu were considered fully anesthetized when they no longer could maintain equilibrium and opercular movements decreased appreciably. Anesthetized fish were placed ventral side up in a padded V-shaped surgery cradle, and a constant stream of anesthetic solution was passed over their gills. Two to four rows of scales were removed at the incision site located anterior to the pelvic fins and just to the left of the ventral midline to avoid cutting through the highly vascularized muscular tissue (Cooke et al. 2012).

A 2-cm incision was made through the abdominal body wall parallel to the long axis of the fish with a disposable #11 scalpel blade. While making the incision, rat-toothed forceps were used to hold the skin and muscle away from the internal organs. The transmitter was inserted into the peritoneal cavity and positioned to the right of the viscera. To close the incision, three to four 3-0 polyethylene sutures were tied using the simple interrupted suture technique (Summerfelt and Smith 1990; Underwood et al. 1998; Morris et al; 2000; Brown et al. 2002). After sutures were tied, a thin layer of 3M™ Vetbond (3M, St. Paul, Minnesota) was applied to the incision site to help seal and strengthen the suture knots (Underwood et al. 1998; Morris et al. 2000; Brown et al. 2002; Wagner and Cooke 2005). Once the first suture was completed, the ventilation water was switched from the anesthetic solution to freshwater to decrease the post-surgical recovery time (Underwood et al. 1998; Morris et al. 2000; Brown et al. 2002; Wagner and Cooke 2005). Following surgery, fish were place in a recovery tub containing freshwater and were released when they exhibited normal behaviors (e.g., maintained equilibrium, responded to a stimulus, and opercular movements returned to normal rates; Anderson et al. 1997). Although fish weight was not recorded, the transmitter to fish weight ratio was significantly lower than the conventional 2% rule (Winter 1996), based on inferring the weight of tagged inconnu with FL ≥ 820 mm to weight-length relationships developed from Yukon River inconnu (Brown 2000).

*Data collection*

The acoustic receiver chosen for this study was the Vemco VR2W single channel datalogger station (Vemco, Halifax, Nova Scotia, Canada). This receiver consisted of an omnidirectional hydrophone, receiver, acoustic transmitter identification detector, data-logging memory, and battery. All receiver components were housed within a submersible case and the aforementioned equipment was used to detect, identify, and record acoustic signals transmitted from passing tagged inconnu. Prior to initial deployment in 2010, the receiver was programmed with the appropriate map code (map-112) provided from the manufacturer. With this map code, the receiver constantly scanned the appropriate tag frequency (69 kHz) until detection occurred, at which point the signal was analyzed to determine the individual code. Acoustic tag transmissions were recorded as long as tagged fish remained within the reception range of the receiving station. Each detection record consisted of a unique tag code and a date and time stamp. These receivers had a battery life of 15 months and can store one million detections.

The reception range for the receiving stations was estimated by towing a tag behind a boat at various distances from multiple receiving stations while using a Vemco VR100 acoustic receiver with a directional hydrophone on the boat to record the total number of acoustic pulses emitted by the tag. The number of detections logged by both the receiving stations and the VR100 receiver were then compared to estimate the detection radius. This estimate was determined as the distance from the receiving station where 100% of the detections would be logged. For my study, a detection radius of 450 m was estimated using my range-testing data during the ice-free period. Dick et al. (2009) determined detection radius of Vemco VR2 receivers to be approximately 400 m with the V9 series tags, while the estimate from Vemco was listed at 539 m under optimal (i.e., water temperature, conductivity, depth, and noise) conditions.

To describe movements of tagged inconnu, an array of 20 VR2W receivers was distributed throughout Hotham Inlet and Selawik Lake. The distribution of the receivers occurred as follows: mouths of the Selawik, Kobuk, and Noatak rivers (n = 3), Selawik Lake (n = 2), and throughout Hotham Inlet (n = 15; Figure 1.2). Receiver locations in Hotham Inlet and Selawik Lake were identified with assistance from members of the

Native Village of Kotzebue and Savereide (2002). The receiving station locations were based on areas that support traditional inconnu harvest. In addition, some receiving stations were deployed in areas where inconnu are not typically harvested to also determine areas that are not used by this species (A. Whiting, Native Village of Kotzebue, personal communication).

The initial deployment of the receiving stations occurred in September 2010. These stations were recovered and subsequently redeployed in July 2011 following cleaning, battery replacement, and data recovery. Final retrieval of the stations occurred in July 2012. During receiver placement, the latitude and longitude of each station was recorded using a wide-angle augmentation system (WAAS) enabled global positioning system (GPS) receiver (Oregon® 450t; Garmin Ltd., Olathe, Kansas). The design of the mooring system consisted of a 36.4-kg concrete block with two, 1.9-cm x 15.2-cm galvanized eye bolts entrapped within the block. A 2-m section of braided nylon boat anchor line (13 mm in diameter) was attached to both eye bolts. A bullet-shaped crab-pot float (15.24 cm x 35.56 cm) was affixed to the top of the anchor line. The VR2W receiver was attached 0.5 m from the base of the concrete block using the manufacture–supplied plastic zip ties. Additionally, a 10-m section of rope was attached to the eye bolts, and a 0.5-kg concrete block was secured to the end of the line (Figure 1.3). During deployment, this rope was laid parallel with the substrate. In July 2011 and 2012, grappling hooks were used to snag this rope for retrieval.

To reduce the risk of receiving station loss from ice entrapment and movement during the winter period, a locator acoustic transmitter was attached to each crab-pot float

(Model V13L; VEMCO, Halifax, Nova Scotia, Canada). These tags were 13 mm in diameter and 36 mm in length, and had a power output of 147 dB. The tags were programmed to turn on 273 days after deployment and emit continuous pings every 7 s at four preprogrammed frequencies (51, 54, 57, and 60 kHz). To relocate deployed receivers, a Vemco VR100 acoustic receiver was used with a directional hydrophone.

*Data analysis*

The acoustic receiving stations recorded the date, time, and unique fish code for each fish that passed within its reception radius. Because each receiving station was geo-referenced at deployment, these data, upon wireless download, were assigned general latitude and longitude coordinates in a projected coordinate system (e.g., Universal Transverse Mercator) using a general linear model in the geographic information system (GIS) software ArcView® 10 (Environmental Systems Research Institute [ESRI], Redlands, California). From this analysis, a spreadsheet was created in Microsoft Excel that contained fields on the fish-identification frequency, the latitude and longitude, and date and time of passage near the receiving station. Inspection of the spreadsheet indicated that there was substantial pseudoreplication (i.e., repeated detections from an individual fish at a single station) present, which was expected based on the passive tracking system used for this study. Pseudoreplication was ameliorated by condensing daily temporally and spatially successive fish detections into a single detection, and all additional data analyses used this reduced data set. The condensed single detection received the date of first detection. To determine if there were differences in length distributions of tagged fish, a Kruskal-Wallis one-way analysis of variance was used to compare the four inconnu tagging events between during 2010 and 2011 in the Selawik and Kobuk rivers. All statistical analyses were considered significant at $\alpha = 0.05$.

Based on previous research that indicated that inconnu begin their up upstream spawning migrations under the ice in late April and May (Alt 1977), the winter period was defined as the time between October 1 and April 30 and the summer period was defined as the time between May 1 and September 30. The winter period for this study included the period after inconnu spawned and returned to the overwintering grounds until May when inconnu initiate their spawning migration. The summer period occurred from the time when inconnu ascended and subsequently descended their respective rivers for spawning. Therefore, summer period data (i.e. presence of tagged fish in the study area) were from non-spawning fish that remained within the Hotham Inlet/Selawik Lake complex.

To describe movements of inconnu, the total number of monthly fish detections at each receiving station was standardized by dividing the number of detections at each geo-referenced station by the total monthly detections for all stations to allow for meaningful interpretation of movements among months. This standardization was conducted on each respective river stock. For each month, these data were plotted with a circle diameter corresponding to the standardized number of fish detections (i.e., the larger circle, the greater the number of detections) on a Hotham Inlet/Selawik Lake map using the computing environment R, version 2.14 (http://www.r-project.org). Qualitative trends in river stock movements for each month were interpreted by viewing the monthly-standardized receiving station maps.

Fish movement distances were estimated by measuring the distance between successive relocations of an individual fish with the cost-path analysis tools in ArcView® 10. Movement rates were quantified for individual fish by dividing the distance between sequential locations by the number of days between locations (m/day; Knights et al. 2002). Distances were measured as the shortest linear distance through water from the last receiver location and, therefore, likely will underestimate the actual distance traveled. Because of underestimation, the daily displacement rates calculated were interpreted as a minimum estimate of daily displacement (hereafter referred to as daily displacement). The daily displacement estimates were pooled by respective river and by month. Bootstrapped 95% confidence intervals (1,000 replications) for mean daily displacement rates were produced because the data failed to meet the assumption of statistical independence.

Mixed-stock aggregations between fish from the two rivers were elucidated by identifying, on a daily basis, when one/multiple tagged fish from one river system was located at the same receiving station as one/multiple tagged fish from the other river system. Because there was a 450-m detection radius encircling the receiving station, mixed-stock aggregations assumed that inconnu from each stock were in close proximity to each other. To determine the spatial and temporal pattern of stock aggregations, these data were plotted three dimensionally, with sampling week (x-axis), sampling station (y-axis), and the number of tagged fish that comprised the daily aggregation on the vertical (z-axis), as the three plot axes. Plots were qualitatively assessed to determine spatial and temporal patterns of mixed-stock aggregations. Statistical analyses were performed using the computing environment R and associated packages, version 2.14.

## Results

The mean fork length of tagged inconnu from the Selawik River was 917 mm (SE = 7.19; range, 820–1060 mm) in 2010 and 889 mm (SE = 5.09; range, 820–1030 mm) in 2011. Mean fork length of tagged inconnu from the Kobuk River was 903 mm (SE = 6.42; range, 820–1037 mm) in 2010 and 909 mm (SE = 6.37; range, 820–1089 mm) in 2011. Median FL for captured fish were not significantly different between sampling year and sites ($H = 7.65$, $P = 0.11$). Prior to the 2010 tracking period, one tagged Kobuk River inconnu was captured by a subsistence fisher and one tagged Selawik River inconnu was captured in June 2011 in the Native Village of Selawik. No other inconnu mortalities were reported during the study period.

Between July 6 and July 26, 2011, 18 of the 20 receiving stations were recovered from Hotham Inlet and Selawik Lake and subsequently re-deployed (Figure 1.2). The final recovery of the 18 receiving stations occurred over a 3-d period from July 21 and 23, 2012. The two stations that were not recaptured were located in the mouth of the Noatak River and also where Selawik Lake terminates and Hotham Inlet originates (Figure 1.2). A total of 128,686 detections were logged from 117 and 101 individually tagged inconnu in the Selawik and Kobuk rivers, respectively, during both years of this study. After the removal of pseudoreplication, the total number of detections was reduced to 8,306 detections.

A greater number of fish detections occurred in 2011/2012 than 2010/2011. The 2010/2011 winter period (October 1, 2010 – April 30, 2011) yielded 1,148 and 866 detections from 46 and 42 unique fish from the Selawik and Kobuk rivers, respectively. One tagged Kobuk River inconnu was detected on September 28, 2010; however, this fish was not detected again during the winter period. The mean number of detections for individual fish was 25 (SE = 3; range, 1–62 detections) and 21 (SE = 3; range, 1–64 detections) for inconnu Selawik and Kobuk rivers, respectively. The 2011/2012 winter period (October 1, 2011 – April 30, 2012) yielded 2,011 and 1,815 detections from 102 and 91 unique fish from the Selawik and Kobuk rivers, respectively. The mean number of detections for individual fish was 20 (SE = 2; range, 1–75 detections) and 20 (SE = 2; range, 1–62 detections) for inconnu from the Selawik and Kobuk rivers, respectively.

Similar to the winter period, a greater number of fish detections occurred in the second summer of sampling (2011/2012) than in the first summer (2010/2011). The 2011 summer period (May 1, 2011 – September 30, 2011) yielded 514 and 513 detections from 46 and 40 unique fish from the Selawik and Kobuk rivers, respectively. The mean number of detections for individual fish was 11 (SE = 1; range, 1–25 detections) and 13 (SE = 1; range, 2–36 detections), for inconnu from the Selawik and Kobuk rivers, respectively. The 2012 summer period (May 1, 2012 – July 23, 2012) yielded 740 and 699 detections from 53 and 49 unique fish from the Selawik and Kobuk rivers, respectively. The mean number of detections for individual fish was 14 (SE = 1; range, 1–34 detections) and 14 (SE = 1; range, 3–39 detections) for inconnu from the Selawik and Kobuk rivers, respectively.

*Movements*

During winters 2010/2011 and 2011/2012, inconnu from both Kobuk and Selawik rivers were initially distributed throughout Hotham Inlet and Selawik Lake (October; Figures 1.4 and 1.5). As the wintering period progressed, the majority of fish detections from both stocks were recorded in the northern end of Hotham Inlet. Although this trend continued throughout the remainder of the winter period, fish were detected moving between Selawik Lake and Hotham Inlet from January to April (Figures 1.4 and 1.5).

During summers 2011 and 2012, May detections followed patterns observed the previous April, with the majority of inconnu from both stocks occurring within the northern end of Hotham Inlet (Figures 1.4 and 1.5). As the summer progressed (June to September), patterns of detection shifted from Hotham Inlet to the entire Hotham Inlet/Selawik Lake complex. However, detections were predominately in Selawik Lake and the south end of Hotham Inlet in August and September (Figures 1.4 and 1.5).

*Movement rates*

During winter 2010/2011, the highest daily displacement estimates for both inconnu stocks occurred in October (Figure 1.6). After this month, there was a precipitous decline in daily displacement for both stocks, and movements remained relatively constant from November through April for both stocks (Figure 1.6). Similarly, daily displacement estimates remained stable throughout the entire 2011/2012 wintering period and coincided with 2010/2011 estimates (Figure 1.6). However, October 2011 daily displacement estimates were lower than 2010 estimates, and Selawik River inconnu had higher daily displacement estimates than Kobuk River inconnu. The largest daily displacement recorded from the Selawik and Kobuk rivers during winter months was 29,044 and 36,685 m/d, respectively.

Average daily displacement estimates for both stocks during the 2011 and 2012 summer ranged predominantly between 2,000 and 4,000 m/day (Figure 1.6). However, an increase in daily displacement was observed in June, with a subsequent decline to previous levels in July. Daily displacements remained consistent for the remainder of the summer period. With the exception of the October 2011 daily displacements, the summer and winter displacement estimates were similar for this study. The largest daily displacement recorded for the Selawik and Kobuk rivers during summer months was 46,111 and 32,673 m/d, respectively.

*Fish aggregations*

During the 2010/2011 and 2011/2012 winter period, 250 and 442 aggregations, respectively, were identified where at least one Kobuk River inconnu was detected at the same station on the same day with at least one Selawik River inconnu (Figure 1.7). On multiple occasions, more than one fish was at the same station as multiple fish from the other stock. During both winter periods, the majority of daily aggregations occurred in the northern Hotham Inlet region. The largest number of aggregations with the greatest number of unique fish occurred from October through December in both years (Figure 1.7).

In summers 2011 and 2012, 144 and 198 aggregations, respectively, were identified where at least one Kobuk River inconnu was detected at the same station on the same day with at least one Selawik River inconnu (Figure 1.8). During both years, the patterns of aggregations at the beginning of the summer period resembled the winter period and aggregations were greatest in the northern Hotham Inlet region. Although aggregations occurred less frequently as the summer progressed, the aggregations that did occur were detected at the Selawik Lake and southern Hotham Inlet receiving stations (Figure 1.8).

**Discussion**

My study is the first documented account of inconnu movements within freshwater lake and estuarine environments in North America, and represents the first telemetry study in the Arctic that focused on movements not directly associated with spawning migrations. Prior to my study, all previous inconnu telemetry research in North America had focused on determining spawning site location and the timing of spawning migrations (Underwood et al. 1998; Brown 2000; Howland et al. 2000). As a result, my study expanded our current knowledge of inconnu life history. Additionally, my study results completed the overall cycle of Kotzebue region inconnu movements by elucidating the overwintering and summer feeding distributions of adult inconnu from the Selawik and Kobuk rivers.

The large number of mixed-stock aggregations during the winter, particularly in the northern end of Hotham Inlet, observed in this study support previous anecdotal evidence from traditional ecological knowledge and tag-return observations. Prior to my study, it was believed, with evidence from tag-return studies and local-resident observations, that inconnu move throughout both Hotham Inlet and Selawik Lake in large mixed-stock schools during the winter (Geiger 1968; Alt 1969; Georgette and Loon 1993;

Underwood 2000). This observation came from local anglers who spent time locating inconnu; once fish were located, hundreds of inconnu were often harvested in a short period of time. Once inconnu stopped biting, experienced ice fishermen noted which direction the aggregation was traveling and followed them (Georgette and Loon 1993). In my study, having multiple fish from each stock at individual receiving stations over the course of short time periods could indicate that these fish are in fact moving through Hotham inlet as large mixed-stock aggregations during the winter period.

The environmental conditions that influence the mixed-stock aggregating behavior exhibited by inconnu have yet to be defined. Alt (1969, 1987) speculated that inconnu overwintering in Selawik Lake moved in response to the movement of their prey (e.g., whitefishes *Coregonus* spp., isopods *Mesidotea entomon*, and opossum shrimp *Mysis relicta*). A local Kotzebue resident reported that stomach contents of inconnu harvested in Hotham Inlet during winter months contained rainbow smelt *Osmerus mordax*, Pacific herring *Clupea harengus pallasi*, and saffron cod *Eleginus gracilis* (P. Goodwin, Kotzebue resident, personal communication). Merritt and Raymond (1983) examined the stomach contents of one inconnu in November 1979 and 68 inconnu in summer 1980, and their results were consistent with this observation. Therefore, prey availability may be a determining factor influencing the movements of inconnu in this region.

In contrast to the winter period, where the majority of inconnu detections were within the northern end of Hotham Inlet, the majority of summer detections from both stocks were at the two stations in Selawik Lake, while the rest were in the southern end of

Hotham Inlet. The summer months are the period when these fish initiate their upriver spawning migrations. The upstream spawning migration of inconnu begins with a slow movement of spawning and non-spawning fish feeding in the lower reaches of the Selawik or Kobuk rivers (Alt 1969). Spawning fish move to upriver spawning sites later in the summer, while non-spawning fish remain in the lower reaches feeding (Alt 1969). As a result, inconnu detected in the study area during the summer period had deferred spawning for at least one spawning cycle. Previous studies, summarized by Alt (1987), have determined that non-consecutive year spawning inconnu travel up to 80 km above the village of Kiana on the Kobuk River for summer feeding. During the summer months, inconnu are also known to roam the brackish waters of Kotzebue Sound. Inconnu in my study being detected in Selawik Lake and the southern end of Hotham Inlet during the summer months would indicate that these fish are moving to summer feeding areas as described by Alt (1987). In addition, inconnu may have moved outside the boundaries of the study area into Kotzebue Sound.

The movements and distribution patterns observed were generally similar to Alt's (1987) previous description. The spring season, however, was a period that exhibited a difference from Alt's description with inconnu moving to summer feeding areas one month later. Additionally, daily displacements corresponded to seasonal movement shifts, with increased displacement occurring during the seasonal transitions of spring to summer and summer to winter. Although most monthly means of daily displacement were generally similar for both river stocks between sampling years, the estimates from October 2010 and 2011 were substantially different. However, the answer to why displacement estimates were different could not be determined and is therefore, attributed to interannual variation and lack of active tracking schedule. Overall, my results add to a more refined description of Alt's (1987) summary of the seasonal movement patterns of inconnu.

The findings of my project indicate that under ice gill-net subsistence harvest (Savereide 2002) occurs while there is large overlap temporally and spatially between the two stocks. This pattern of temporal-spatial overlap exhibited by Kotzebue region inconnu may have consequences for future sustainably of these two stocks because properly managing a mixed-stock fishery typically requires an accurate description of the stock composition of the fishery (Kalinowski 2004). For example, if at some time one of the Kotzebue region inconnu stocks become depressed to the point where harvest guidelines need to be implemented, initiating stock-specific guidelines would be difficult to develop because of the strong overlap between these stocks. Management options could include, but would not be limited to, subsistence harvest season regulations (i.e., harvest quotas) and marine protected areas where high overlap occurs. Harvest quotas have been successfully implemented in other Alaskan mixed-species fisheries, such as the Chatanika River personal-use whitefish spear fishery located near Fairbanks, Alaska (Brase and Baker 2011). In the Chatanika River fishery, species-specific harvest guidelines are not feasible because fish cannot be identified by species prior to spear harvest. Identifying and designating protected areas where overlap occurs between the two stocks would lower the risk of overfishing the smaller Selawik River stock. Ultimately, managers must identify harvest regulations that allow for the long-term sustainability of the smaller Selawik River stock. Without knowledge of the contributions to total harvest by each stock, these recommendations must remain conservative to maintain the viability of the smaller Selawik River stock.

As with all field studies, limitations occurred that must be acknowledged for data interpretation. For example, the ultimate fate of tagged fish that were never detected within the system remains unknown. During my study, 68% of the tagged fish were relocated and there are multiple interpretations on why fish were not detected during the sampling period, which could include mortality due to secondary infection of the surgical site (Walsh et al. 2000), predation because of altered swimming performance (Adams et al. 1998), or failure to report capture of tagged fish by subsistence fishers. Based on discussions with local residents from Kotzebue and the villages located on the Kobuk and Selawik rivers, the most likely cause for non-detection of tags is the failure to report capture of tagged fish. There were reports of tagged fish being caught in the villages, but contacting these harvesters did not yield any information. The two tagged inconnu that were captured by subsistence fishers were healthy in their opinion, and therefore, I assume that mortality due to post-surgical infection to be minimal for my study. In this region of Alaska, with the exception of humans, there are very few predators (e.g., marine mammals) of adult inconnu. As a result, mortality by predators, other than humans, due to altered swimming performance (if any) is considered to be negligible.

Additional sampling limitations associated with my study could reside with the receiver equipment. Detection problems would be signal collisions between successive fish at the same stations, fish traveling through the detection radius of the receiving station without the acoustic tag sending an acoustic pulse, or the possibility of faulty tags. Additionally, tagged fish may not have been using the areas around the receiving stations, and therefore, the stations were not placed in the appropriate locations. Because this study did not have complete spatial coverage, fish movements could not be tracked continuously. Receiving stations were only able to monitor 0.05% of the total study area; as a result, there was a large amount of area available (i.e., Selawik Lake) to inconnu than what was monitored. However, based on the study design, receiving stations were placed in areas where inconnu were known to frequent and also areas that were thought to have lower inconnu residency. The largest area of non-coverage occurred within Selawik Lake. This was due to depth constraints during the ice-covered period of the lake (i.e., depth of liquid water available under the ice cover). Therefore, the risk of ice entrapment would have been great if receiving stations had been deployed in the shallow waters of Selawik Lake. A solution to the low spatial coverage in Selawik Lake would have been to use a mobile hydrophone to track tagged inconnu.

Other potential overwintering and summer feeding areas may not have been represented by this study as well. Because the receiving station at the mouth of the Noatak River could not be recovered, the potential usage of this river could not be determined in my study. Alt (1987) captured inconnu in spawning condition near the now closed Noatak River hatchery. Additionally, Taube and Wuttig (1998) discovered that inconnu were captured in the Buckland River in fall 1997. As a result, further studies on inconnu movements into Kotzebue Sound, Selawik Lake, and associated rivers are warranted.

For future acoustic tagging research in the Kotzebue region, some recommendations can be made for refining methods, including the number of tagged fish, receiving stations, and the locations of receiving station deployments for large scale movement studies. To monitor a larger area and increase the probability of detection, more receiving stations should be used in this region. A financial trade off to increasing the number of receiving stations is reducing the number of tagged fish. Future studies could deploy 100 tags per river and double the number of receiving stations that could be deployed at the same cost. Because my results indicate that adult inconnu exhibit similar movement patterns between years and stocks, finer scale movement data of a smaller amount of fish would outweigh the benefits of coarser scale movement data of a larger amount of fish. The locations for receiver deployment should be chosen to create gates across geographic areas to facilitate fish detection, which could include the transition zone from Selawik Lake to Hotham Inlet and also Hotham Inlet to Kotzebue Sound. This may require placing rows of stations across each gate to ensure detection of inconnu, which can rapidly pass through a single gate. For large-scale movements, additional stations should also be placed in Kotzebue Sound along with locations in the Noatak, Buckland, Kobuk, and Selawik rivers.

My study has increased our understanding of the inconnu movement patterns in the Kotzebue region thus, more informed management strategies may now be developed if the information from my recommendations are incorporated within the context of other study results. However, many questions regarding the biology and ecology of inconnu remain unanswered. Given the importance of inconnu as a subsistence resource, future research should focus on identifying movement patterns of juvenile and immature inconnu, the extent and timing of movement within Selawik Lake, feeding habits of inconnu within this region, and the importance of Kotzebue Sound for inconnu movement. Future research should also focus on identifying habitat characteristics that are beneficial for this species.

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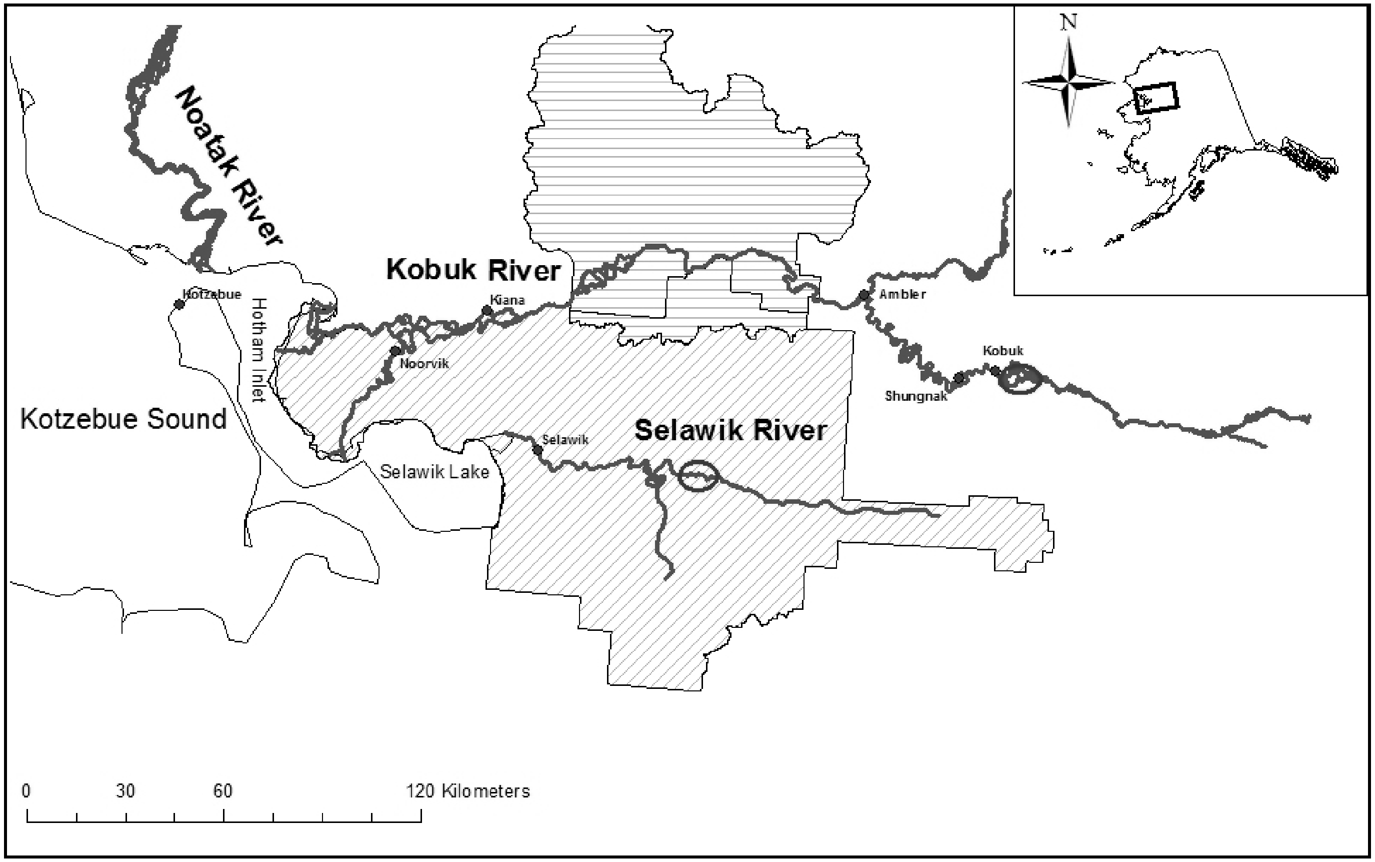


Figure 1.1 Map of the study area. The Selawik National Wildlife Refuge is indicated by the diagonal gray lines, while the Kobuk Valley National Park is indicated by the horizontal gray lines. Inconnu sampling sites are located in the circles on the upper Selawik and Kobuk rivers.

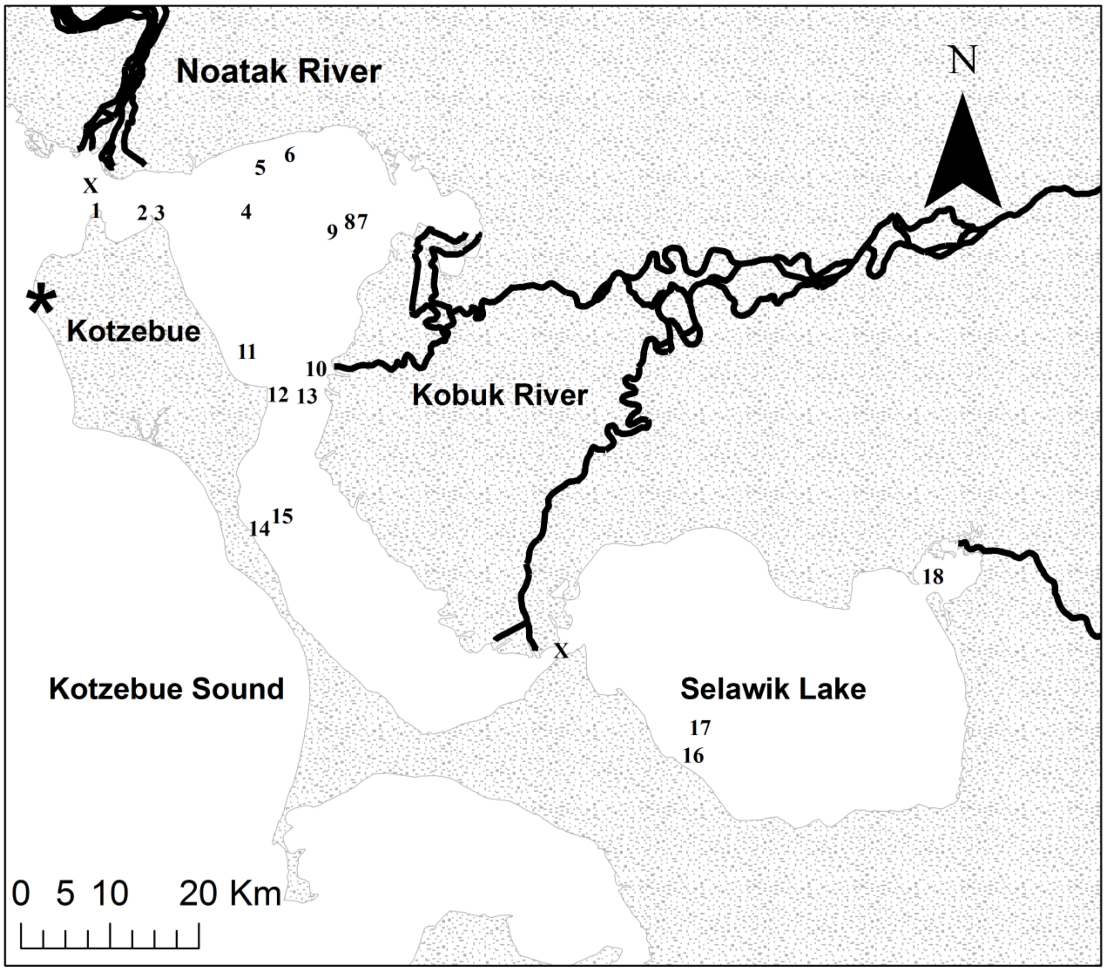


Figure 1.2. Map of Hotham Inlet and Selawik Lake depicting locations of receiving stations. The receiving stations are identified by number (n = 18), with unrecovered stations identified with the letter X (n = 2).

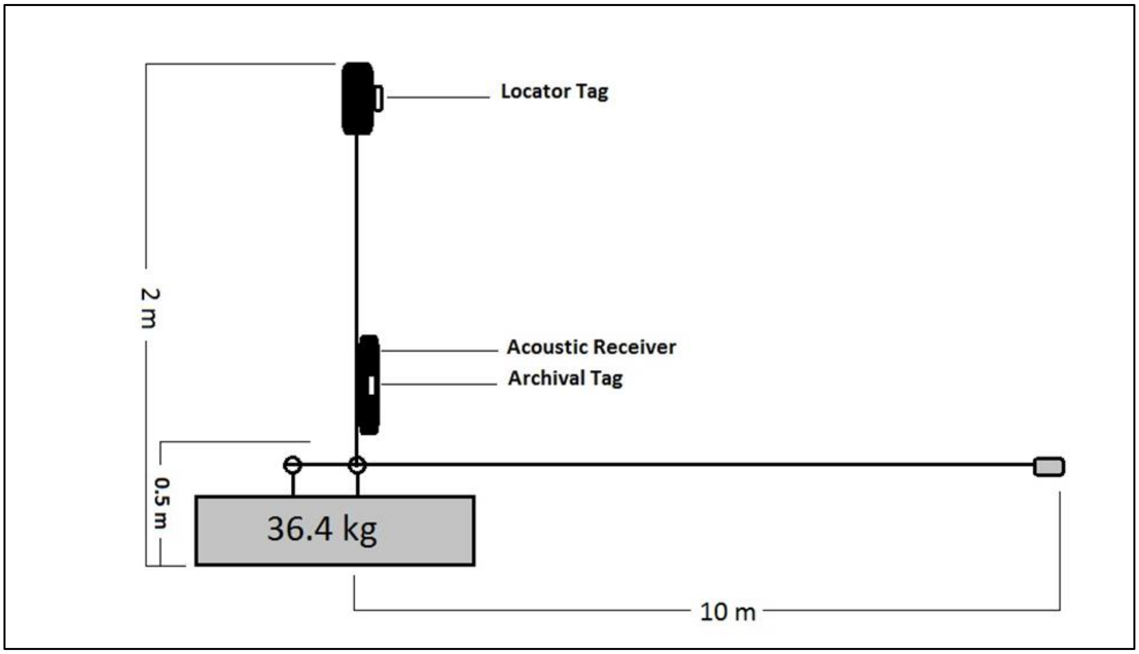


Figure 1.3. Depiction of a completed acoustic receiving station with mooring system.

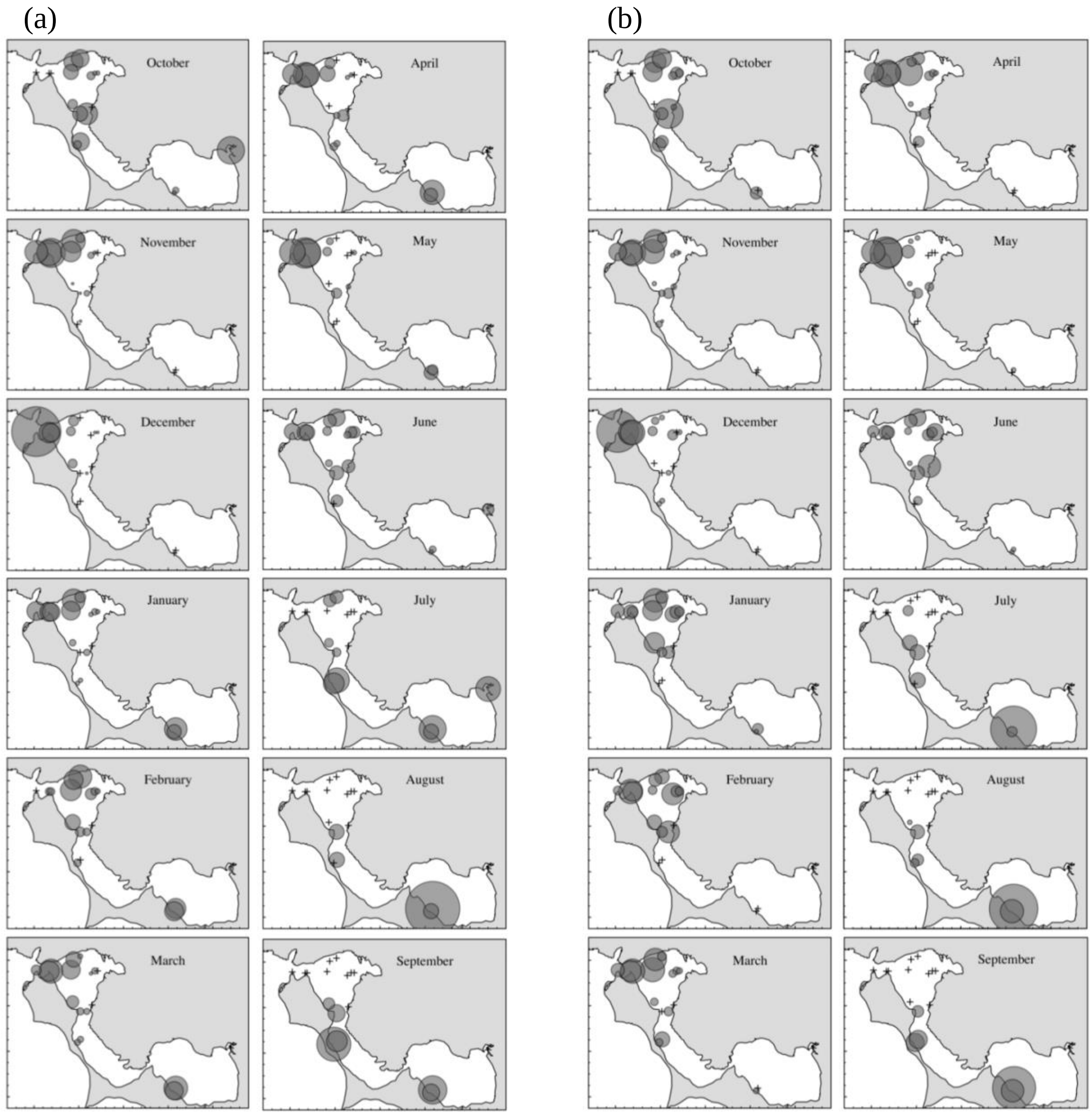


Figure 1.4. Monthly standardized station usage maps for 2010/2011 Selawik (a) and Kobuk River (b) inconnu. A larger circle indicates higher monthly usage and a cross indicates no usage.

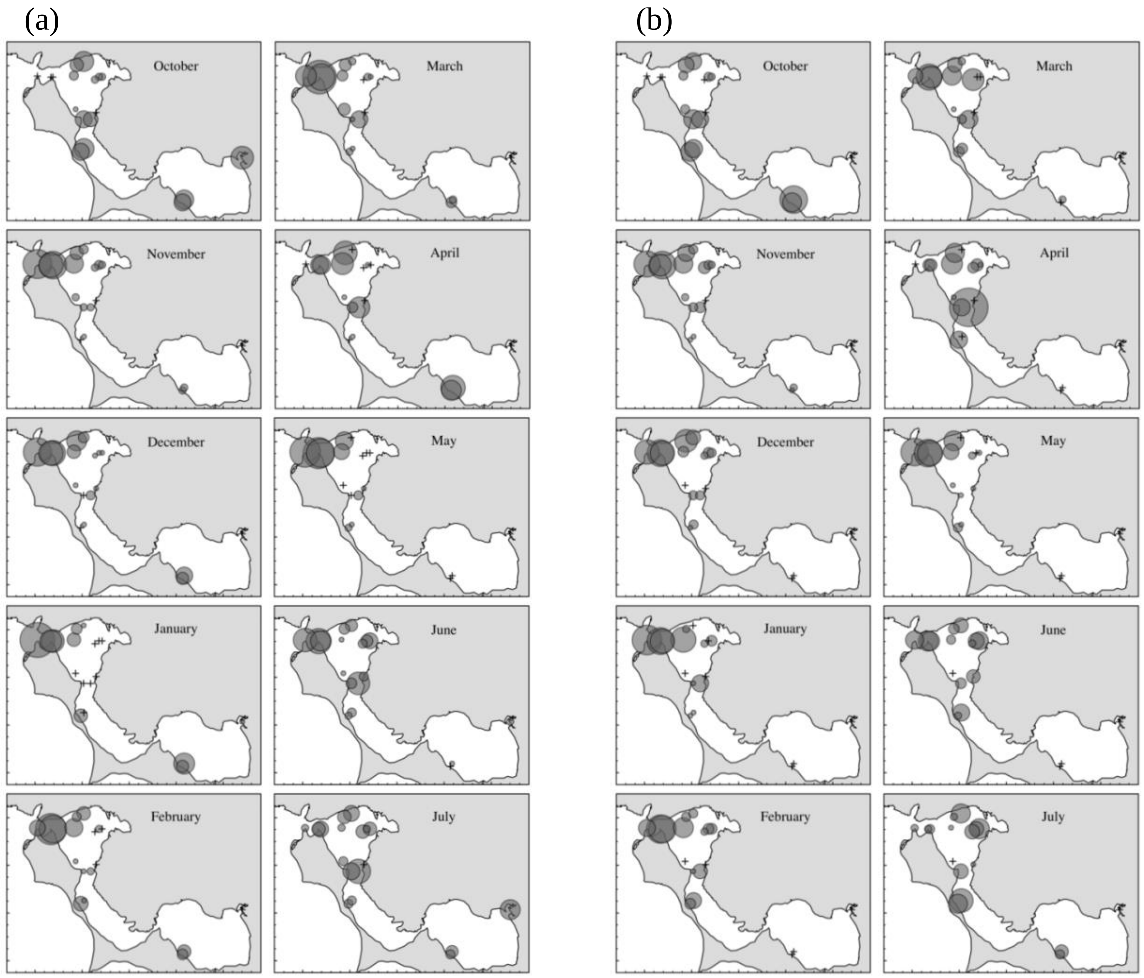


Figure 1.5. Monthly standardized station usage maps for 2011/2012 Selawik (a) and Kobuk River (b) inconnu. A larger circle indicates higher monthly usage and a cross indicates no usage.

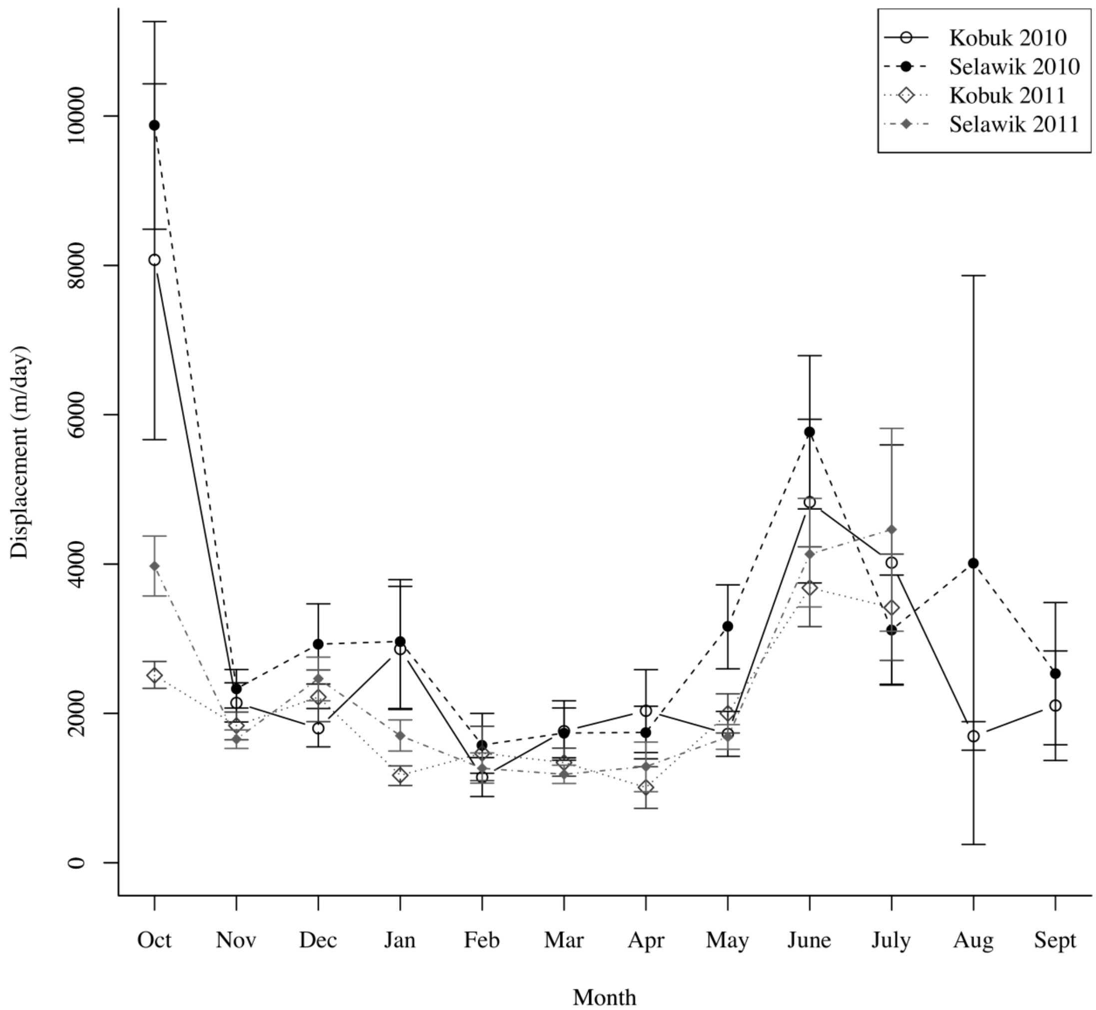


Figure 1.6. Mean monthly minimum daily displacement (m) estimates with bootstrapped 95% CI for inconnu from the Selawik and Kobuk rivers.

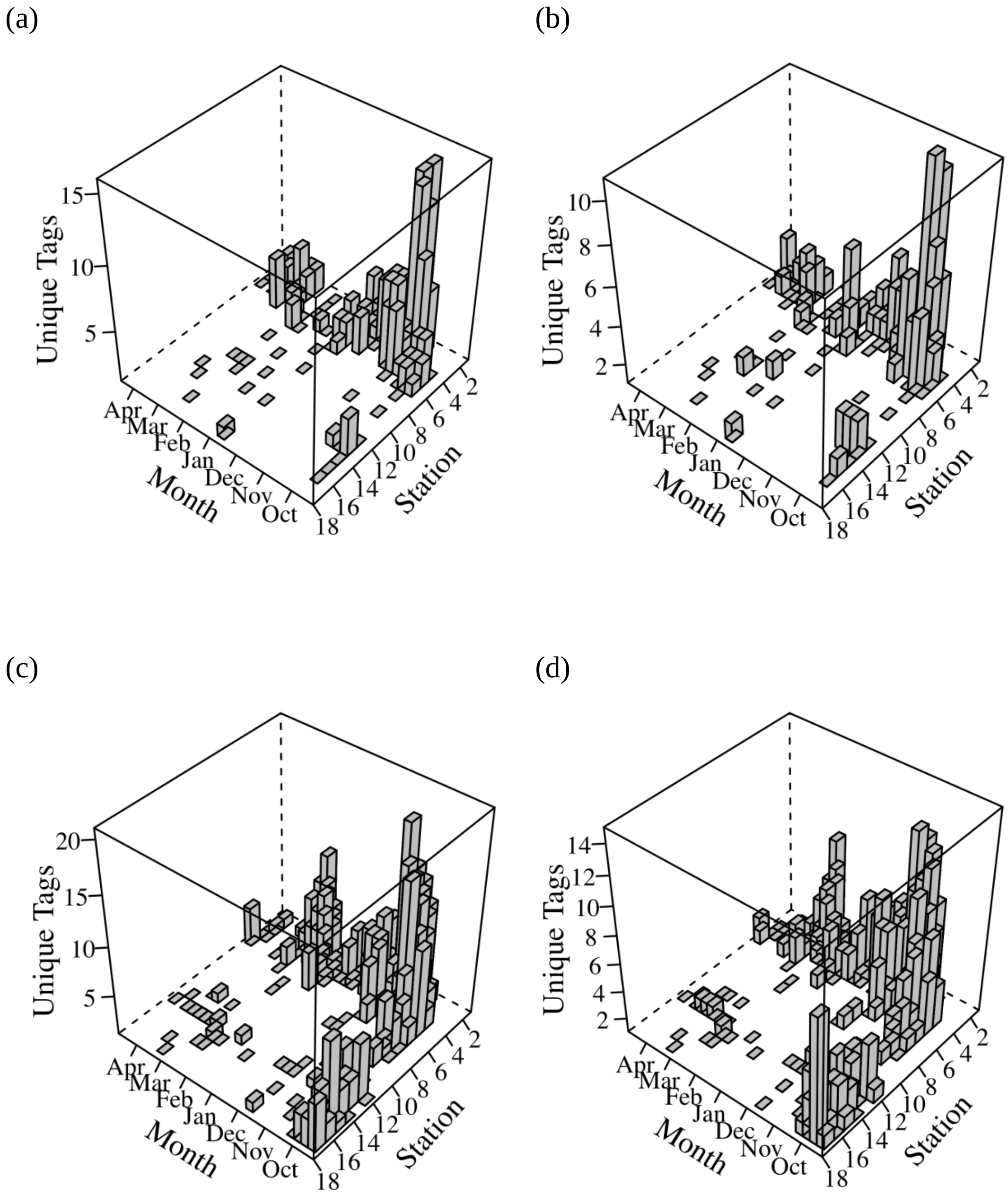


Figure 1.7. Winter daily aggregations for inconnu in 2010/2011 for the Selawik (a) and Kobuk (b) rivers and in 2011/2012 for the Selawik (c) and Kobuk (d) rivers. Bar height indicates how many individually tagged fish made up the daily aggregation. See Figure 1.2 for station locations.

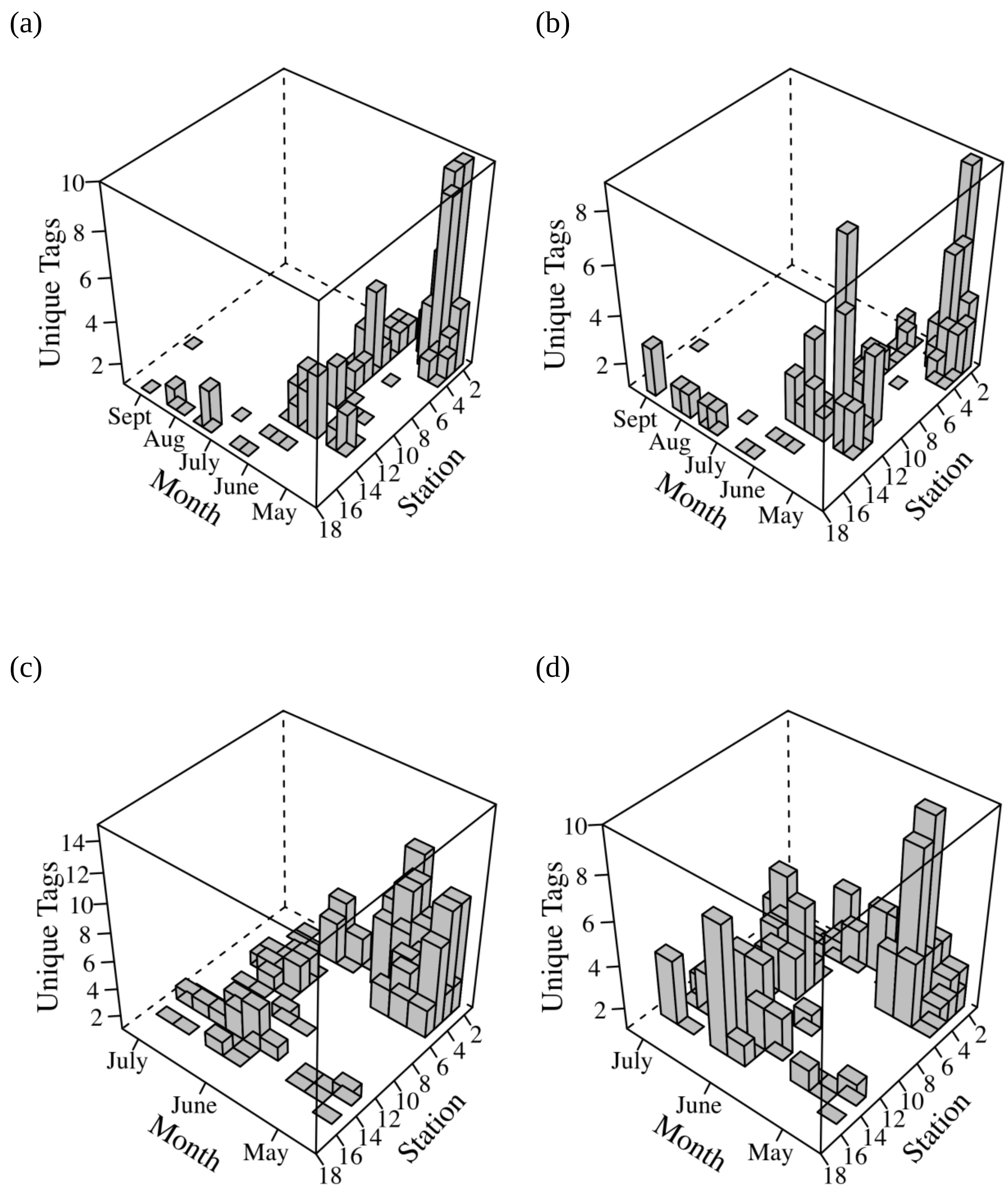


Figure 1.8. Summer daily aggregations for inconnu in 2010/2011 for the Selawik (a) and Kobuk (b) rivers and in 2011/2012 for the Selawik (c) and Kobuk (d) rivers. Bar height indicates how many individually tagged fish made up the daily aggregation. See Figure 1.2 for station locations.

# Chapter 2: Seasonal habitat occupancy of inconnu from the Selawik and Kobuk rivers[2]

## Abstract

Inconnu *Stenodus leucichthys* are one of the most important fishes harvested in the Kotzebue region of Alaska for subsistence purposes. My study was conducted to describe the seasonal habitat occupancy of inconnu in the Selawik and Kobuk River drainages, Alaska, from 2010 through 2012. Data collection methods consisted of surgically implanting acoustic telemetry tags in 80 fish from both rivers in 2010 and 2011 (n = 320), and deploying a fixed array of 20 Vemco VR2W acoustic receiving stations affixed with archival tags throughout Selawik Lake and Hotham Inlet. During my study, inconnu were detected at water temperatures and salinities ranging from -1.39 to 18.69ºC and 0 to 31.3 psu, respectively. No stock-specific or temporal trends in habitat occupancy by inconnu were detected during this study. Inconnu occupied colder water temperatures during winter months and they occupied the coldest and warmest water temperatures during the summer months. Inconnu occupied the entire range of salinities present during both summer and winter seasons, but generally occupied water of >5 psu. In addition to providing a more thorough account of inconnu life history, these results provide valuable baseline information about inconnu that can be used for future habitat comparisons.

[2]Smith, N. J. and T. M. Sutton. 2013. Seasonal habitat occupancy of inconnu from the Selawik and Kobuk rivers. Prepared for submission in Transactions of the American Fisheries Society.

**Introduction**

The inconnu *Stenodus leucichthys* (sheefish) is the largest of the whitefish species (subfamily: Coregoninae; Scott and Crossman 1973). Specimens of this long-lived, piscivorous whitefish as large as 100 cm in length and 15 kg in weight are not uncommon (Alt 1969; Scott and Crossman 1973; Brown 2000). Inconnu are found in the Arctic and subarctic waters of North America, Asia, and the Caspian Sea (Alt 1969; Scott and Crossman 1973) and, in Alaska, inconnu support important subsistence, sport, and commercial fisheries (Alt 1988). The main stocks of inconnu in Alaska are located in the Kuskokwim, Yukon, Kobuk, and Selawik River drainages as amphidromous and riverine populations (Alt 1987, 1988).

Inconnu from the Selawik and Kobuk rivers have common overwintering grounds within Hotham Inlet and Selawik Lake and were historically considered to be a single stock (Alt 1969, 1987), however, genetic analysis (Miller et al. 1998) and traditional tag-return studies (Taube and Wuttig 1998; Underwood 2000) have concluded that they are separate, distinct spawning stocks. After spawning in late September and early October, Kotzebue region inconnu migrate downstream from their natal rivers and overwinter in Selawik Lake (freshwater) and Hotham Inlet (brackish water, with a gradient of higher salinity toward Kotzebue Sound; Underwood 2000). Although inconnu have been captured in winter fisheries throughout Hotham Inlet and associated waterways (Taube 1996, 1997; Taube and Wuttig 1998; Underwood et al. 1998; Underwood 2000), knowledge about their habitat characteristics during this period is unknown.

In the Kotzebue region of Northwestern Alaska, inconnu are one of the most important food fishes in the region, with 20,000+ fish harvested each year in subsistence, sport, and commercial fisheries (Georgette and Loon 1990; Taube 1997; Savereide 2002; Georgette and Koster 2005; Georgette and Shiedt 2005). In 1980, the United States Congress recognized the importance of inconnu and identified the Selawik River stock as a species of special interest under the Alaska National Interest Lands Conservation Act (ANILCA). With this classification, Congress mandated that inconnu be maintained in their natural diversity and that opportunities for subsistence use are maintained.

Recently, the Arctic has garnered much attention with respect to global warming (Reist et al. 2006). Between the mid-19th and mid-20th centuries, the Arctic region warmed to its highest temperatures in 400 years (Overpeck et al. 1997). One outcome associated with warmer temperatures in the Arctic is altered hydrologic regimes (Prowse et al. 2006). Predicted shifts in lentic and lotic systems in the Arctic include delayed freeze-up, earlier ice break-up, higher autumn water temperatures, and reduced ice thickness. Impacts associated with Arctic estuarine systems are reduced ice cover, a shorter duration of ice cover, and increased freshwater inputs during summer months, which is likely to increase stratification (Prowse et al. 2006). For fishes, the effects due to climate change may be positive or negative as well as species and location specific. However, water temperature effects can range from range expansions into other systems to extirpation from historically important drainages due to higher summer water temperatures and reduced flows (Reist et al. 2006).

In addition to climate-induced changes, an application has recently been approved to the Native Village of Selawik for the development of an ice road between the Native Village of Selawik and an inholding with the Selawik National Wildlife Refuge (SNWR). It is believed that there will be an increase in the demand for ice roads in this area. Water drawdowns are required for ice-road development, which could negatively impact the quantity and quality of habitats for inconnu (L. Ayres, U.S. Fish and Wildlife Service [USFWS] SNWR, personal communication). Based on these concerns and the importance of inconnu as a fisheries resource, there is a need to understand the winter habitat occupancy of inconnu in the Kotzebue region. The specific objective of this study was to describe the seasonal water temperature and salinity occupancy of inconnu in the Selawik and Kobuk rivers. To fulfill this objective, I utilized acoustic telemetry and deployed an array of automated receiving stations affixed with archival tags throughout the Selawik and Kobuk River drainages. The results of this study will not only increase our basic understanding of inconnu life-history characteristics, but also provide resource managers with the baseline data to determine potential effects of anthropogenic- and climate-induced environmental changes. These results will allow managers to make informed management decisions concerning Kotzebue region inconnu.

## Study Area

The study area for this project, located in northwestern Alaska, included the Selawik and Kobuk River drainages, which are comprised of the Selawik River, Kobuk River, Selawik Lake, and Hotham Inlet (Figure 2.1). An area at the mouth of the Noatak River was a region of additional focus because inconnu have been captured at various times of the year by local Noatak River residents and this location was thought to possibly provide important winter refuge for inconnu (Figure 2.1; Alt 1987). Portions of the study area were located within the SNWR as well as the Kobuk Valley National Park (KVNP; Figure 2.1).

The Selawik River, which is designated a National Wild River, originates in the Purcell Mountains and flows 300 km within a wide tundra valley to termination within Selawik Lake. The Kugarak River (flowing from the north) and Tagagawik River (flowing from the south) are the two major tributaries of the Selawik River. Originating in the Endicott Mountains, the Kobuk River flows west approximately 800 km through the KVNP and SNWR and terminates at Hotham Inlet. Both rivers become highly braided near their outlets. Selawik Lake is third largest lake in Alaska, and is approximately 42 km in length and 30 km in width. This lake has a surface area of 1,050 $km^2$, has depths up to 5.5 m, and is a freshwater system that flows west into Hotham Inlet. The inlet is 80 km in length, ranges from 8 to 32 km in width, has depths up to 7 m, and is an arm of the Kotzebue Sound. Hotham Inlet is bounded on the southwest by the Baldwin Peninsula and is an outlet for the Selawik and Kobuk rivers. This inlet is a brackish water system with the northern end having mixed salinities ranging from 7 to 23 ppt. The southern end of the inlet is stratified with a deep layer of freshwater (0 ppt) above a thin saline layer (25 ppt) during periods of ice cover. Water temperatures within Hotham Inlet and Selawik Lake range from 0 to 2.1ºC during the winter period (R. Brown, USFWS, personal communication).

This region of Alaska has a maritime climate during ice-free periods of the year (typically late May to early October), and transitions to an Arctic climate during the winter months. Air temperatures range from approximately 34ºC in the summer to -50ºC in the winter. The annual average precipitation ranges between 38 and 51 cm (USFWS 1993).

## Methods

### *Fish capture*

During July and August 2010 and 2011, 80 inconnu were captured each year from the Selawik and Kobuk rivers (160 fish per river, 320 fish total) during their upstream spawning migration. Only fish larger than 820 mm in fork length (FL) were retained to ensure that only spawning adults were tagged (Hander et al. 2008). Sampling in the Selawik River occurred within the vicinity of Kerulu Creek (Figure 2.1), an area sampled during a mark-recapture population estimation study conducted by Hander et al. (2008). Kerulu Creek is located approximately 25 km downstream of the documented inconnu spawning area and 200 km upstream from the mouth of the Selawik River. Kobuk River sampling occurred from the Native Village of Kobuk to approximately 1 km downstream of the Pah River (Figure 2.1). This river reach is approximately 550 km upstream from the Kobuk River mouth, and includes documented spawning areas (Alt 1987; Taube and Wuttig 1998). Previous studies have indicated that inconnu exhibit spawning site fidelity (Miller et al. 1998; Taube and Wuttig 1998; Underwood 2000); therefore, it was assumed that inconnu caught at each respective river sampling site were residents of each specific river stock.

Hook-and-line angling and haul seines were the gear types used for this study (Taube 1996; Taube and Wuttig 1998; Underwood et al. 1998; Underwood 2000). A heavy spinning rod and reel with 9.072-kg test monofilament and a single barbless Krocodile spoon (Luhr Jensen, Hood River, Oregon) was used for hook-and-line sampling. Based on previous research, Stuby and Taube (1998) concluded that hooking mortality of inconnu using angling gear was low (single-hook mortality = 1.6%). During my biological sampling, no incidents of hooking mortality were recorded and I assumed hooking mortality to be zero based on the behavior of fish post-capture. To capture inconnu with haul seines (3.3 m in depth and 61.5 m in length, with 25-mm bar mesh), a boat was used to deploy the net on the inside of shallow river bends. Prior to deployment, 16-m leads were attached to both ends of the seine. To deploy the seine, two sampling crew members were positioned on shore holding one lead, while the boat pulled the seine perpendicular to the current. As the boat deployed the seine, onshore sampling crew members walked the net down the shore line to accomplish a straight deployment. Once deployed, the net was allowed to drift for approximately 300 m. The boat motored to shore and the two ends were brought together at the conclusion of the drift. The net was then pulled onto shore, leaving a section in the water to contain captured inconnu until they were processed

*Transmitter specifications*

Vemco V9TP-2L-coded acoustic transmitters were surgically implanted into candidate inconnu in both sampling years. These acoustic transmitters were 9 mm in diameter and 47 mm in length, weighed 3.5 g in water, and a had power output of 143 dB

(Vemco, Halifax, Nova Scotia, Canada). In addition to being individually coded, each tag was equipped with a temperature (range, -4 to 200$^{o}$C) and pressure (depth; up to 50 m in depth) sensor. Transmitters had an expected battery life of 609 d and transmitted at 69 kHz with a nominal delay of 180 seconds (range, 110–250 sec) between transmissions. Although the acoustic transmitter was capable of measuring depth, no analyses were conducted using water depth data because the Hotham Inlet/Selawik Lake complex is shallow (station depth range, 3.3 to 6 m) and the manufacturer's depth error range for the acoustic transmitters was very broad (±2.5 m).

*Surgical methods*

Upon capture, fish were placed in a holding tub containing freshwater and were visibly examined for physical injury and signs of exhibiting a stress response. Stress response included erratic swimming, cloudy retinas, and pale coloring (Underwood et al. 1998). No fish were disqualified from my study due to physical injury or stress. Fork length (FL) was measured to the nearest 1 mm and additional data collected for each fish included location, date, and time of fish capture, capture method, time of release, and the environmental conditions during the sampling period. Prior to surgery, all surgical instruments and transmitters were disinfected with chlorhexidine and rinsed with freshwater before use and new sterile gloves were worn for the duration of each surgical procedure.

After physical examination, candidate inconnu were placed in a 100-L holding tub containing a clove oil (20–30 mg/L) anesthetic solution (Anderson et al. 1997; Prince and Powell 2000; Borski and Hodson 2003; Brown 2006). Inconnu were considered fully anesthetized when they could no longer maintain equilibrium and opercular movements decreased appreciably. Once anesthetized, fish were placed ventral side up in a padded V-shaped surgery cradle, and a constant stream of anesthetic solution was delivered to their gills. Two to four rows of scales were removed for the incision site located anterior to the pelvic fins and just to the left of the ventral midline. This area was chosen to avoid cutting through the highly vascularized muscular tissue of the linea alba (Cooke et al. 2012).

Using a disposable #11 scalpel blade, a 2-cm incision was made through the abdominal body wall parallel to the long axis of the fish. Rat-toothed forceps were used to hold the skin and muscle away from the viscera during the incision. The transmitter was inserted in the abdominal cavity and positioned to the right of the viscera. Three to four 3-0 polyethylene sutures were tied using the simple interrupted suture technique to close the incision (Summerfelt and Smith 1990; Underwood et al. 1998; Morris et al. 2000; Brown et al. 2002). A thin layer of 3M™ Vetbond (3M, St. Paul, Minnesota) was applied to the incision site to help seal and strengthen the suture knots (Underwood et al. 1998; Morris et al. 2000; Brown et al. 2002; Wagner and Cooke 2005). The ventilation water was switched from the anesthetic solution to fresh, anesthetic-free water when the first suture was completed in order to decrease the post-surgical recovery time (Underwood et al. 1998; Morris et al. 2000; Brown et al. 2002; Wagner and Cooke 2005). Following surgery, fish were placed in a recovery tub containing fresh water and were released when they exhibited normal behaviors (e.g., maintained equilibrium, opercular movements returned to normal rates, and responded to a stimulus; Anderson et al. 1997).

*Data collection*

Vemco VR2W single channel datalogger stations (VEMCO, Halifax, Nova Scotia, Canada) were chosen as the acoustic receiver for this study. The components of each datalogger station were: (1) an omnidirectional hydrophone; (2) receiver; (3) acoustic transmitter identification detector; (4) data-logging memory; and (5) battery. Receiver components were housed in a submersible case. The aforementioned equipment was used to detect, identify, and record acoustic signals transmitted from passing tagged inconnu. The acoustic receiver was programmed with the manufacturer supplied map code (map-112) prior to deployment. With the map code, the receiver continually scanned the appropriate tag frequency (69 kHz) until detection occurred, at which point the signal was analyzed to determine the individual code. Tag transmissions were recorded for as long as fish remained in the detection range of the receiving station. Upon detection, the receiver recorded the unique tag code and environmental data, along with a date and time stamp. Expected battery life of the receivers was 15 months. Receivers were capable of storing one million detections, weighed 170 g in water, and were 308 mm in length and 73 mm in diameter.

The reception range for the receiving stations was estimated by towing a tag behind a boat at various distances from multiple receiving stations while using a Vemco VR100 acoustic receiver with a directional hydrophone on the boat to record the total number of acoustic pulses emitted by the tag. The number of detections logged by both the receiving stations and the VR100 receiver were then compared to estimate the detection radius. This estimate was determined as the distance from the receiving station where 100% of the detections would be logged. For my study, a detection radius of 450 m was estimated using my range-testing data during the ice-free period. Dick et al. (2009) determined detection radius of Vemco VR2 receivers to be approximately 400 m with the V9 series tags. The estimate from the manufacturer was listed at 539 m under optimal conditions.

To describe habitat occupancy of tagged inconnu, an array of 20 VR2W receivers was distributed throughout Hotham Inlet and Selawik Lake. The distribution of the receivers occurred as follows: mouths of the Selawik, Kobuk, and Noatak rivers (n = 3), Selawik Lake (n = 2), and throughout Hotham Inlet (n = 15; Figure 2.2). Receiver locations in Hotham Inlet and Selawik Lake were identified with assistance from members of the Native Village of Kotzebue and the published literature (Savereide 2002). The receiving station locations were based on areas that support traditional inconnu harvest. In addition, some receiving stations were deployed in areas where inconnu are not typically harvested to also determine areas that are not used by this species (A. Whiting, Native Village of Kotzebue, personal communication).

The initial deployment of the receiving stations occurred in September 2010. These stations were recovered and subsequently redeployed in July 2011 following station cleaning, receiver battery replacement, and data recovery. The final retrieval of the stations occurred in July 2012. During receiver placement, the latitude and longitude of each station was recorded using a wide-angle augmentation system (WAAS) enabled global positioning system (GPS) receiver (Oregon® 450t; Garmin Ltd., Olathe, Kansas). The design of the mooring system consisted of a 36.4-kg concrete block with two, 1.9-cm x 15.2-cm galvanized eye bolts entrapped within the block. A 2-m section of braided nylon boat anchor line (13 mm in diameter) was attached to both eye bolts. A bullet-shaped crap-pot float (15.24 cm x 35.56 cm) was affixed to the top of the anchor line. The VR2W receiver was attached 0.5 m from the base of the concrete block using the manufacturer supplied plastic zip ties. Additionally, a 10-m section of rope was attached to the eye bolts and a 0.5-kg concrete block was attached to the end of the line. During deployment, this rope was placed parallel with the substrate. In July 2011 and 2012, grappling hooks were used to snag this rope for retrieval.

To reduce the risk of receiving station loss from ice entrapment and movement during the winter period, a locator acoustic transmitter was attached to the crab-pot float (Model V13L; VEMCO, Halifax, Nova Scotia, Canada). These tags were 13 mm in diameter and 36 mm in length, and had a power output of 147 dB. The tags were programmed to turn on 273 days after deployment and emit continuous pings every 7s at four preprogrammed frequencies (51, 54, 57, and 60 kHz). To relocate deployed receivers, a Vemco VR100 acoustic receiver was used with a directional hydrophone.

*Habitat monitoring*

To identify environmental conditions occupied by inconnu, 20 Star-Oddi (Star-Oddi Marine Device Manufacturing, Reykjavik, Iceland) archival tags were affixed to the acoustic receiving stations. Archival tags were chosen in addition to acoustic tags because they were capable of continuously measuring water temperature and salinity, an attribute the acoustic tags lacked. The archival tag (model DST CTD) chosen for this study had a battery life of four years and could store 130,000 measurements per sensor.

The archival tag was programmed to record water temperature (range, -1.00 to 40.00$^{o}$C) and salinity (measured as conductivity; range, 3.0 to 37.0 µS/cm) every hour while deployed. Upon retrieval, all data were transferred via an archival tag communication box for subsequent analysis using the SeaStar Software provided by the manufacturer. Seastar Software was also used to convert conductivity (µS/cm) to salinity (psu) using standard conversion algorithms (Fofonoff and Millard 1983). In addition, psu and ppt units are equivalent (Stickney 2009)

*Data analysis*

For the purposes of this study, the winter period was defined as the time between October 1 and April 30 and the summer period was from May 1 to September 30. The winter period for this study included the period after inconnu spawned and returned to the overwintering grounds until spring when inconnu initiated their spawning migration. The summer period occurred when inconnu ascended and subsequently descended their respective rivers for spawning. Therefore, summer period data (i.e. presence of tagged fish in the study area) was from fish that were not spawning and remained within the Hotham Inlet/Selawik Lake complex. These time periods were chosen based on previous research that indicated that inconnu begin their up upstream spawning migrations under the ice in April and May (Alt 1977). To determine if there were differences in length distributions of tagged fish, a Kruskal-Wallis one-way analysis of variance was used to compare among the four inconnu tagging events during 2010 and 2011 in the Selawik and Kobuk rivers.

Two data sets were used to analyze the seasonal habitat occupancy of inconnu. The first data set was comprised of water temperature measurements that were logged by the acoustic receiving station when a fish was detected by a station (hereafter referred to as acoustic data). Because water temperatures were not recorded at every fish detection and salinity was measured by an archival tag affixed to the receiving station, a second data set was constructed with this information. This spreadsheet (hereafter referred to as archival data) was comprised of water temperature and salinity data from the Starr-Oddi archival tags, and was merged to fish detection data based on the closest time at detection to the closest measurement taken by the archival tag. Archival data assumed that the water temperature and salinity recorded at the receiving station were similar to the water temperature and salinity values at the position of the detected fish. Both data sets were aggregated by month, acoustic receiver, and stock of origin, and mean monthly values were computed for the temperature and salinity measurements. In addition, the number of individually tagged fish (IDs) from each river stock that were detected at each station during the monthly period were calculated and added to the spreadsheet. If no fish were detected at a specific station during a particular month, the mean monthly water temperature and salinity was calculated from the archival tag data and added to the archival data set.

To model habitat occupancy, the archival data set was used. The response variable for modeling was the number of unique IDs detected, while the explanatory variables included water temperature and salinity nested within stock of origin. Non-nested models were also constructed to determine if the two inconnu stocks occupied different habitats.

Semi-parametric and non-parametric generalized additive models (GAM), with a Gaussian error distribution that had an identity link function, were used for this modeling process because of non-linear relationships between the response and explanatory variables. A Gaussian error distribution was chosen over other error distributions (e.g., Possion, negative binomial, zero-inflated, etc…) because the data from this study followed a normal probability density function. Generalized additive models have the ability to capture non-linear trends with the use of smoothed non-linear functions of explanatory variables (Wood 2006). The general formula of the GAM (Equation 1) was:

$$g(\mu) = \beta_o + \sum_{i=1}^{p} f_i(X_i), \qquad \text{(Equation 1)}$$

where $g$ was the link function, $\mu$ was the expectation of observations, $\beta_o$ was the intercept, $X_1,\ldots,X_p$ were independent variables, and $f_i$ was the non-parametric or smoother function.

The flexibility of GAMs requires that prior to model fitting and selection, steps must be taken to produce relevant results. Care must be taken when fitting GAMs to avoid producing spurious relationships, which may result from over fitting of data. To correct for over-fitting of data without compromising model fit, a gamma of 1.4 was specified during model fitting (Kim and Gu 2004; Wood 2006). During the model-fitting routine, the gamma term inflates the candidate model degrees of freedom, which alters the generalized cross-validation score that the GAM algorithm utilizes to determine the proper smoothing parameters. When necessary, parametric or non-parametric variables for month and station were added to account for temporal or spatial autocorrelation. To determine the appropriate parameter for month and station, each variable was added to a model as a non-parametric parameter and, if the estimated degrees of freedom (edf) was >1, the non-parametric parameter was kept in the model. If the edf was 1, a parametric parameter was used for model fitting. Residual diagnostics indicated that a natural log plus one (ln+1) transformation of the response variable was needed to correct for normality. Model selection utilized Akaike's Information Criterion with a second-order bias correction (AICc) and parsimony (Burnham and Anderson 2004). If two competing models had a ΔAICc ≤ 7, the most parsimonious model was chosen (Burnham et al. 2011). The general full model (Equation 2) used for occupancy modeling was:

$$\ln(\text{Unique IDs} + 1) = \beta_0 + \beta_1(\text{Month}) + f_{1k}(\text{Temperature}) + f_{2k}(\text{Salinity}) + f_4(\text{Station}) + \varepsilon, \qquad \text{(Equation 2)}$$

where $\beta_o$ and $\beta_1$ were the regression parameters for the intercept and month, respectively, $f$ was the smoother term added to each explanatory variable, and k denoted river.

Using the acoustic and archival data, GAMs were also used to determine if the two river stocks of inconnu occupied different water temperatures and salinities during the seasonal periods. The full model (Equation 3) nested month within the factor river:

$$\text{Temperature or Salinity} = \beta_0 + f_{1k}(\text{Month}) + f_3(\text{Station}) + \varepsilon, \qquad \text{(Equation 3)}$$

where $\beta_o$ and $\beta_1$ were the regression parameters for the intercept and month, respectively, $f$ was the smoother term added to each explanatory variable, and k denoted river.

Data inspection revealed that one archival tag had a salinity sensor that malfunctioned; as a result, all salinity data from that tag was removed from subsequent analyses. Also, in one instance of model selection, an adjustment was made for the interpretation of the GAM results. The ΔAICc of the best-fit model for winter 2011/2012 data was -7.64. Although this value was above the cut off value, inspection of the actual response yielded no difference in interpretation and did not add evidence that there was a difference between rivers. Finally, due to a programming error when re-deploying the receiving stations, the archival tags were not set in record mode from July to September 2011. As a result, the only data available from that time period was the temperature measurement logged by the acoustic tag. Therefore, no comparisons could be made for salinity during the 2011 summer because the short time period monitored would not allow the GAM algorithm to successfully fit a model because of a lack of degrees of freedom ($n = 2$). All statistical analyses were conducted using the computing environment R and associated packages, version 2.14 (http://www.r-project.org).

## Results

Median FL of captured fish were not significantly different between sampling year and sites (Figure 2.3; $H = 7.65$, $P = 0.11$). Prior to the 2010 tracking period, one tagged Kobuk River inconnu was captured by a subsistence fisher and one tagged Selawik River inconnu was captured in June 2011 in the Native Village of Selawik. No other inconnu mortalities were reported during the study period.

Between July 6 and July 26, 2011, 18 of the 20 receiving stations were recovered from Hotham Inlet and Selawik Lake and subsequently re-deployed (Figure 2.4). The final recovery of the 18 receiving stations occurred over a 3-d period from July 21 and 23, 2012. The two stations that were not recaptured were located in the mouth of the Noatak River and also where Selawik Lake terminates and Hotham Inlet originates (Figure 2.2). A total of 128,686 inconnu detections were logged from 117 and 101 individually tagged fish in the Selawik and Kobuk rivers, respectively, during both years of this study.

A greater number of fish detections occurred in winter 2011/2012 than 2010/2011. The 2010/2011 winter period (October 1, 2010 – April 30, 2011) yielded 15,978 and 12,703 detections from 46 and 42 unique fish from the Selawik and Kobuk rivers, respectively. One tagged Kobuk river inconnu was detected on September 28, 2010; however, this fish was not detected again during the winter period. The mean number of detections for an individual fish was 347 (SE = 42; range, 1–1,368 detections) and 303 (SE = 43; range, 4–1,239 detections) for inconnu in the Selawik and Kobuk rivers, respectively. The 2011/2012 winter period (October 1, 2011 – April 30, 2012) yielded 35,138 and 32,905 detections from 102 and 91 unique fish from the Selawik and Kobuk rivers, respectively. The mean number of detections for an individual fish was 345 (SE = 46; range, 1–2,733) detections) and 362 (SE = 45; range, 2–1,964 detections) for inconnu from the Selawik and Kobuk rivers, respectively.

Similar to the winter period, a greater number of fish detections occurred in the second summer of sampling (2012) than in the first summer (2011). The 2011 summer period (May 1, 2011 – September 30, 2011) yielded 4,472 and 6,941 detections from 46 and 40 unique fish from the Selawik and Kobuk rivers, respectively. The mean number of detections for an individual fish was 97 (SE = 13; range, 4–354 detections) and 174 (SE = 27; range, 7–1,478 detections) for inconnu from the Selawik and Kobuk rivers, respectively. The 2012 summer period (May 1, 2012 – July 23, 2012) yielded 9,900 and 10,649 detections from 53 and 49 unique fish from the Selawik and Kobuk rivers, respectively. The mean number of detections for an individual fish was 186 (SE = 28; range, 2–1,099 detections) and 217 (SE = 38; range, 5–1,146 detections) for inconnu from the Selawik and Kobuk rivers, respectively.

Differences in water temperature and salinity were observed between the winter and summer periods. Water temperature ranged from -1.81 to 5.59 and -1.63 to 6.86ºC during the 2010/2011 and 2011/2012 winter periods, respectively. In winter, water temperature was coldest at the northern end of Hotham Inlet and became progressively warmer toward Selawik Lake (Figure 2.4). During the winter periods, water temperature remained relatively stable (range, -1.81 to 2.48ºC) after October (Figure 2.4). Salinity ranged from 0 to 31.8 and 0 to 28.9 psu during the 2010/2011 and 2011/2012 winter periods, respectively. Because the outlet of Hotham Inlet experienced tidal influence, there was a gradient of higher salinity within the Hotham Inlet body. Salinity greater than 0 psu was also measured at the two northwestern receiving stations in Selawik Lake (Figure 2.5). Water temperatures ranged from -1.25 to 7.52 and -1.33 to 19.30ºC during the 2011 and the 2012 summer periods, respectively. Salinity ranged from 0 to 29.8 and 0 to 27.6 psu during the 2010/2011 and 2011/2012 summer periods, respectively. Generally, water temperature and salinity were more variable during summer than winter. During this study, acoustic tags measured that inconnu were detected at water temperatures ranging from -1.39 to 18.69ºC. Archival tags, attached to the receiving stations, measured salinity for detected inconnu that ranged from 0 to 31.3 psu.

*Habitat occupancy and temporal trends*

No stock-specific or temporal trends in habitat occupancy by inconnu were detected over the two winter periods (Tables 2.1 and 2.2). The GAMs for winters 2010/2011 and 2011/2012 showed that the number of individually tagged inconnu from both rivers was greatest at colder waters and lowest at warmer waters (Figure 2.6). The number of individually tagged inconnu during the 2010/2011 winter period was highest at salinities around 8 psu (Figure 2.7). During the 2011/2012 winter period, GAM model results for salinity exhibited an asymptotic relationship with the number of individually tagged fish, peaking and holding constant after 5 psu (Figure 2.7).

Similar to winter periods, no stock-specific or temporal trends in habitat occupancy were detected over the two summer periods (Tables 2.1 and 2.2). The GAMs for water temperature exhibited a peak in the number of individually tagged inconnu at the lowest water temperatures (-1–0 °C), followed by a decline in abundance to 3ºC (Figure 2.6). For warmer water temperatures, a positive trend was observed in 2012 (Figure 2.6). During both summers, GAM model results for salinity exhibited an asymptotic relationship with the number of individually tagged fish, peaking and holding constant after 10 psu (Figure 2.7).

## Discussion

My study revealed that Kotzebue region inconnu exploited a wide range of water temperatures and salinities throughout their annual cycle. Although both stocks are genetically distinct (Miller et al. 1998), no difference in habitat occupancy was detected between these two stocks during any sampling period. These data, along with results that show that inconnu in the Kotzebue region have similar seasonal movement patterns (see Chapter 1) add further support that these populations are a mixed stock while co-located within the Hotham Inlet/Selawik Lake complex during their annual movement cycle.

Because inconnu had the highest occupancy at the coldest water temperatures during both winters, which were located at the northern end of Hotham Inlet immediately outside the transition into Kotzebue Sound, inconnu predominately occupied the colder waters along the edge of Kotzebue Sound. Occupancy of the northern end of Hotham Inlet is corroborated with winter movements of inconnu observed in Chapter 1. Other Arctic whitefishes, such as Arctic cisco *Coregonus autumnalis* and least cisco *C. sardinella*, have been found to overwinter within brackish water deltas and harbors along the Beaufort Sea (Craig 1984, 1989; Schmidt et al. 1989). However, this overwintering behavior is dissimilar to other Alaskan Arctic anadromous fishes (Craig 1984). For example, Arctic char *Salvelinus alpinus* and Dolly Varden char *Salvelinus malma* overwinter within freshwater lakes, pools and groundwater-fed springs of Alaskan rivers that drain into the Beaufort Sea (Craig 1984; Stolarski 2013). In contrast, Arctic char in Norway have been observed occupying estuarine environments with sub-zero water temperatures during winter months (Jensen and Rikardsen 2008). Although Arctic fishes use a variety of strategies to survive the harsh winter period, inconnu appear to use a similar strategy as other whitefishes in Alaskan waters.

Inconnu occupy similar temperatures and salinities as other coregonids and Arctic char. For example, Arctic and least cisco in the Beaufort Sea were sampled when winter water temperatures and salinities ranged from -1.7 to 0ºC and 0 to 32 ppt, respectfully. These species were also collected during summer when water temperatures and salinities ranged from 0 to 14ºC and 2 to 32 ppt, respectfully. Arctic char were sampled during winter when water temperatures ranged from 0 to 2ºC and salinity was 0 ppt, while summer sampling water temperatures and salinities ranged from 0.5 to 14ºC and 2 to 32 ppt, respectively (Craig 1984). Dolly Varden have been detected in ice-covered waters of the Chukchi Sea at water temperatures of -1.4ºC (A. Seitz, University of Alaska Fairbanks, personal communication). While no studies have examined the temperature or salinity tolerances of inconnu, my research indicates that adult inconnu are capable of surviving a broad range of water temperatures (range, -1.39 to 18.69ºC) and salinities (range, 0–31.3 psu).

By virtue of their persistence in the Arctic, inconnu appear to be capable of surviving near freezing water temperatures at relatively high salinities, indicating that they can depress their freezing point. Although the mechanism by which freezing-point depression occurs in inconnu and other Arctic whitefishes is unknown, this adaptation in not uncommon for other fishes, especially marine teleosts (Fletcher et al. 2001; Devries and Cheng 2005). For example, Arctic and Antarctic marine fishes, such as Arctic cod *Arctogadus glacialis*, utilize the production of glycol proteins for freezing-point depression (Chen et al. 1997; Harding et al. 2003; Devries and Cheng 2005). Freezing-point depression has been studied extensively in marine teleosts, but not for freshwater teleosts (Fletcher et al. 2001; Devries and Cheng 2005). For freshwater species such as Arctic char, Atlantic salmon *Salmo salar*, and brown trout *S. trutta*, a change in blood electrolyte balance, along with the epidermis acting as a physical barrier, have been identified as the mechanisms used for freezing-point depression (Fletcher et al. 1988). In the presence of ice crystals suspended in water, Arctic char can resist freezing to -0.9ºC; however, in the absence of these ice crystals, they survived temperatures to -1.7ºC (Fletcher et al. 1988). As a result, a change in blood electrolyte balance may be a mechanism by which inconnu use to depress their freezing point.

In extreme environments, the availability of suitable winter habitat can be reduced relative to warmer periods (Schmidt et al. 1989). In the Kotzebue region, the relatively high productivity and large size of the estuary area provide a unique aquatic habitat for overwintering anadromous and euryhaline fishes (Alt 1969). This uniqueness results from the Selawik and Kobuk rivers draining into large bodies of brackish water (i.e., Hotham Inlet and Selawik Lake) before entering the marine environment, which results in a relatively large amount of warm and productive winter habitat for inconnu in the Kotzebue region. In contrast, the North Slope lacks relatively large delta and lagoon estuarine habitats during much of the year, especially winter. During summer near the termination of Arctic rivers on the North Slope, a nearshore band of warm, brackish water is present along the coast. Arctic marine and freshwater fishes exploit these productive warmer waters for feeding; however, this band is absent during winter and is replaced by colder (-1.9ºC) marine water which excludes fishes that are not freeze tolerant from occupying these areas (Craig 1984). Because of the relatively large amount of overwintering habitat in the Kotzebue region, inconnu are not restricted to small pools, groundwater springs, or minimal brackish water deltas seen in other Arctic rivers.

The habitat results collected during my study have direct implications for the future management of Kotzebue region inconnu. Although it has been understood that these two stocks support a mixed-stock fishery, the degree of mixing was not known (Underwood 2000). My study results add further evidence that these two stocks are a completely mixed stock while they are co-located within the Hotham Inlet/Selawik Lake complex. As a result, it is impossible to target each stock individually in subsistence fisheries.  Therefore, to properly manage these two stocks, the contribution to total harvest must be quantified for each stock (Kalinowski 2004). In the absence of this information, harvest quotas must be set conservatively to maintain the viability of the smaller Selawik River stock.

The results of my study have provided the first documentation that Selawik Lake is a brackish water system and also added additional knowledge about the water temperature and salinity regimes and dynamics of the Hotham Inlet/Selawik Lake complex. A continuous influx of saline waters into the northwestern end of Selawik Lake occurs, but the extent and depth of these saline waters remains unknown. This information will not only help to answer movement and distribution questions concerning inconnu, but also for other whitefishes of this region (Brown 2004). These results can also provide baseline data to allow for the development of a monitoring program to identify changes within the Hotham Inlet/Selawik Lake complex as a result of anthropogenic- and climate-induced changes.

As the cost of basic supplies (i.e., food, fuel, building material) in the Kotzebue region continue to increase, the demand for ice roads that allow residents of rural communities to purchase cheaper items in Kotzebue will continue to increase (USFWS 2011). Currently, an ice road linking Kotzebue to the communities on the Kobuk River is built when winter conditions allow. However, this ice road does not rely on water drawdowns for construction and therefore, poses no direct threat to inconnu (G. Skin, Northwest Arctic Borough Public Services Department, personal communication). A second ice road in this region, which requires water drawdowns for construction, is located between the Native Village of Selawik and an inholding with the SNWR (L. Ayres, USFWS SNWR, personal communication). From my results, the ice road within the SNWR poses little to no risk to adult inconnu because fish from both the Selawik and Kobuk rivers do not occur near the Native Village of Selawik during the ice covered period (see Chapter 1). Because, inconnu from the Selawik and Kobuk rivers overwinter in the northern end of Hotham Inlet, ice roads that require water drawdowns should be avoided in this area to alleviate any unpredicted effects on inconnu.

My study results indicate that inconnu are capable of surviving cold winter water temperatures. Inconnu travel into Kotzebue Sound during summer months (Alt 1987) and along nearshore waters during the winter (Raymond and Merritt 1984), however, their movements have not been examined in offshore waters of Kotzebue Sound. Traditional ice fishers capture inconnu within Kotzebue Sound, and their capture has occurred at locations where salinity is 15 ppt during winter (Raymond and Merritt 1984). Physico-chemical measurements within Kotzebue Sound in March 2005 indicated that there were water temperatures and salinities during March that allowed inconnu to move into Kotzebue Sound (R. Brown, USFWS, unpublished data). Knowledge of physico-chemical attributes within Kotzebue Sound during both summer and winter periods would increase our understanding of the specific seasonal distribution of Kotzebue region inconnu.

One limitation of my study was that it was dependent on data collected at discrete locations; however, the location of a particular detected inconnu was not always at the exact location of a receiving station. Consequently, my study assumes that the habitat around the fish was similar to the habitat adjacent to the receiving station. This assumption may not be true at some stations (e.g., stations 12–16). Salinity was the habitat characteristic most likely to differ between the receiving station and fish locations because the southern part of Hotham Inlet becomes stratified with a layer of freshwater (0 ppt) that lies above a saline layer (25 ppt) during periods of ice cover (R. Brown, USFWS, personal communication). Another caveat of my project was that I monitored only 0.05 % of the total habitat within the study area that was available to inconnu. As a result, it is possible that additional habitat features were not sampled that were available and selected by inconnu.

My study has described the seasonal water temperature and salinity occupancy of Kotzebue region inconnu. While my results have increased our understanding of inconnu biology, which ultimately provides managers with additional information needed to make sound management decisions, there are many key attributes of inconnu life history, which remain unknown. For future research in the Kotzebue region, I recommend that investigations be conducted to determine the amount of useable habitat available during the winter period, assess the extent of saline waters into Selawik Lake, evaluate fine-scale habitat use of mature and immature inconnu, initiate a habit monitoring program, and assess the viability of Kotzebue Sound as an additional overwintering area. Future research should also evaluate blood samples from overwintering inconnu to better understand freezing-point depression for this species. Information from these evaluations will provide a more thorough account of inconnu life history as well environmental relationships in this region of Alaska associate with climate change.

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Table 2.1. Summary output from equation (2), which described inconnu habitat occupancy for the four sampling periods. For each model, AICc, % deviance explained (% dev.exp), and equivalent degrees of freedom (edf) are provided. An asterisk (*) indicates the best-fit model.

| Sampling Period | Model | Predictors | AICc | %dev.exp | edf |
|---|---|---|---|---|---|
| Winter 2010/11 | 1 | Temp/River, Salinity/River, Month | 520.52 | 51.6 | 23.85 |
| | 2 | Temp/River, Salinity, Month | 525.32 | 49.0 | 20.79 |
| | 3 | Temp, Salinity/River, Month | 513.58 | 52.6 | 23.00 |
| | 4* | Temp, Salinity, Month | 519.36 | 49.5 | 19.28 |
| | 5 | Temp, Month | 542.46 | 42.3 | 15.60 |
| | 6 | Salinity, Month | 595.21 | 27.4 | 14.69 |
| Winter 2011/12 | 1 | Temp/River, Salinity/River, Month | 588.82 | 55.4 | 21.56 |
| | 2 | Temp/River, Salinity, Month | 598.58 | 50.5 | 15.35 |
| | 3 | Temp, Salinity/River, Month | 582.14 | 56.6 | 21.63 |
| | 4* | Temp, Salinity, Month | 589.79 | 53.4 | 17.60 |
| | 5 | Temp, Month | 630.06 | 43.2 | 14.75 |
| | 6 | Salinity, Month | 644.06 | 39.9 | 14.94 |
| Summer 2011 | 1 | Temp/River, Salinity/River, Month | 179.20 | 43.8 | 12.41 |
| | 2 | Temp/River, Salinity, Month | 174.46 | 44.5 | 11.13 |
| | 3 | Temp, Salinity/River, Month | 170.36 | 47.0 | 10.78 |
| | 4* | Temp, Salinity, Month | 159.48 | 60.1 | 13.55 |
| | 5 | Temp, Month | 171.02 | 45.2 | 10.22 |
| | 6 | Salinity, Month | 178.25 | 26.3 | 5.27 |
| Summer 2012 | 1 | Temp/River, Salinity/River, Month | 245.12 | 56.2 | 17.65 |
| | 2 | Temp/River, Salinity, Month | 241.90 | 55.8 | 16.20 |
| | 3 | Temp, Salinity/River, Month | 233.02 | 57.1 | 14.17 |
| | 4* | Temp, Salinity, Month | 230.37 | 56.2 | 12.32 |
| | 5 | Temp, Month | 244.85 | 47.1 | 10.54 |
| | 6 | Salinity, Month | 278.38 | 19.9 | 6.89 |

Table 2.2. Summary output from equation (3), which identified temporal differences in inconnu habitat occupancy for the four sampling periods. For each model, AICc, % deviance explained (% dev.exp), and equivalent degrees of freedom (edf) are provided. An asterisk (*) indicates the best-fit model.

| Sampling Period | Model | Predictors | AICc | %dev.exp | edf |
|---|---|---|---|---|---|
| Winter 2010/11 | 1 | Temp/River, Station | 222.11 | 66.5 | 13.45 |
| | 2* | Temp, Station | 218.54 | 66.5 | 12.04 |
| | 1 | Salinity/River, Station | 1023.03 | 52.6 | 12.36 |
| | 2* | Salinity, Month | 1023.50 | 49.5 | 10.68 |
| Winter 2011/12 | 1 | Temp/River, Station | 213.86 | 70.5 | 14.23 |
| | 2* | Temp, Station | 211.97 | 70.2 | 12.48 |
| | 1 | Salinity/River, Station | 1054.20 | 77.2 | 13.72 |
| | 2* | Salinity, Month | 1050.71 | 77.1 | 11.80 |
| Summer 2011 | 1 | Temp/River, Station | 383.82 | 91.3 | 6.99 |
| | 2* | Temp, Station | 380.24 | 91.2 | 5.00 |
| | 1 | Salinity/River, Station | NA | NA | NA |
| | 2 | Salinity, Month | NA | NA | NA |
| Summer 2012 | 1 | Temp/River, Station | 363.25 | 91.7 | 5.23 |
| | 2* | Temp, Station | 361.27 | 91.7 | 4.10 |
| | 1 | Salinity/River, Station | 503.04 | 75.0 | 9.68 |
| | 2* | Salinity, Month | 503.10 | 74.3 | 8.75 |

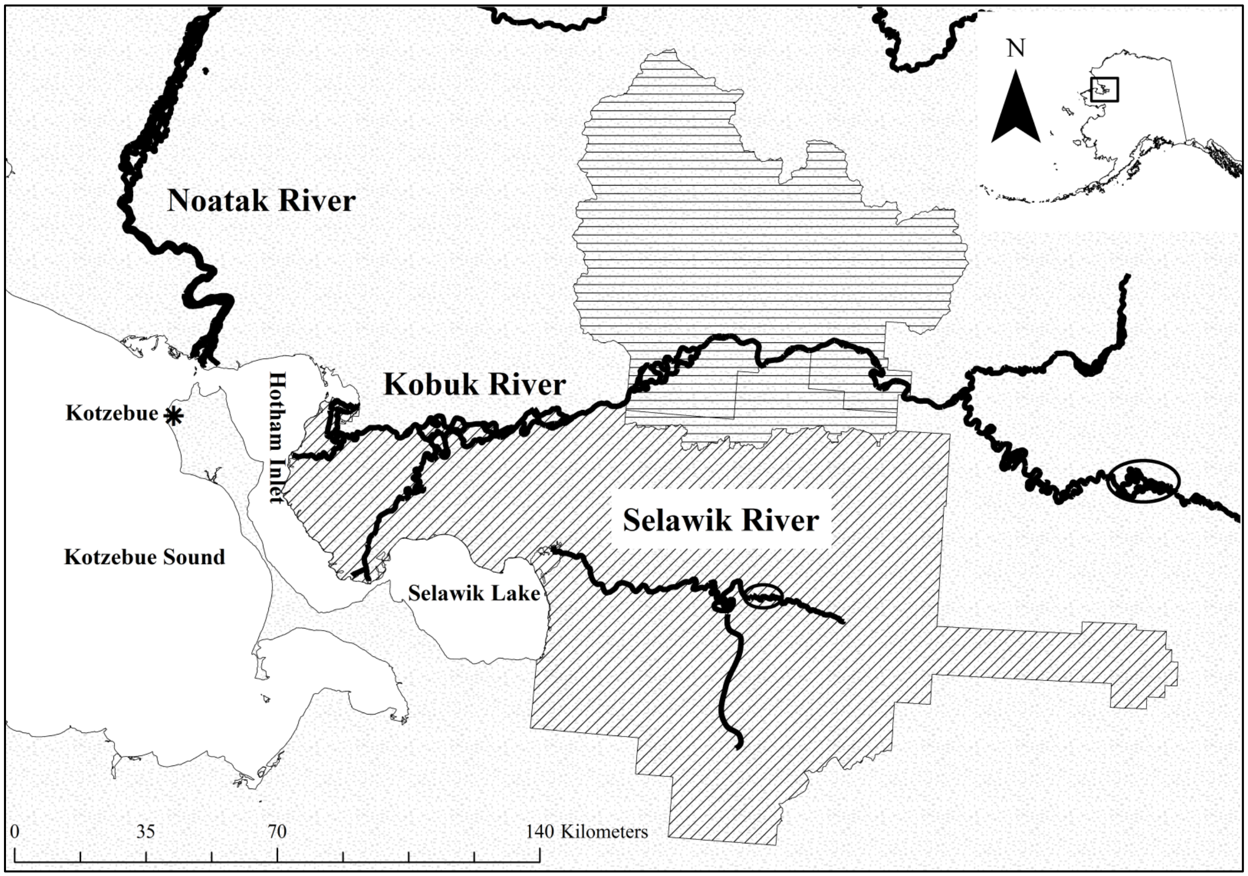


Figure 2.1. Map of the study area. The Selawik National Wildlife Refuge is indicated by the diagonal gray lines, while the Kobuk Valley National Park is indicated by the horizontal gray lines. Inconnu sampling sites are located in the circles on the upper Selawik and Kobuk rivers.

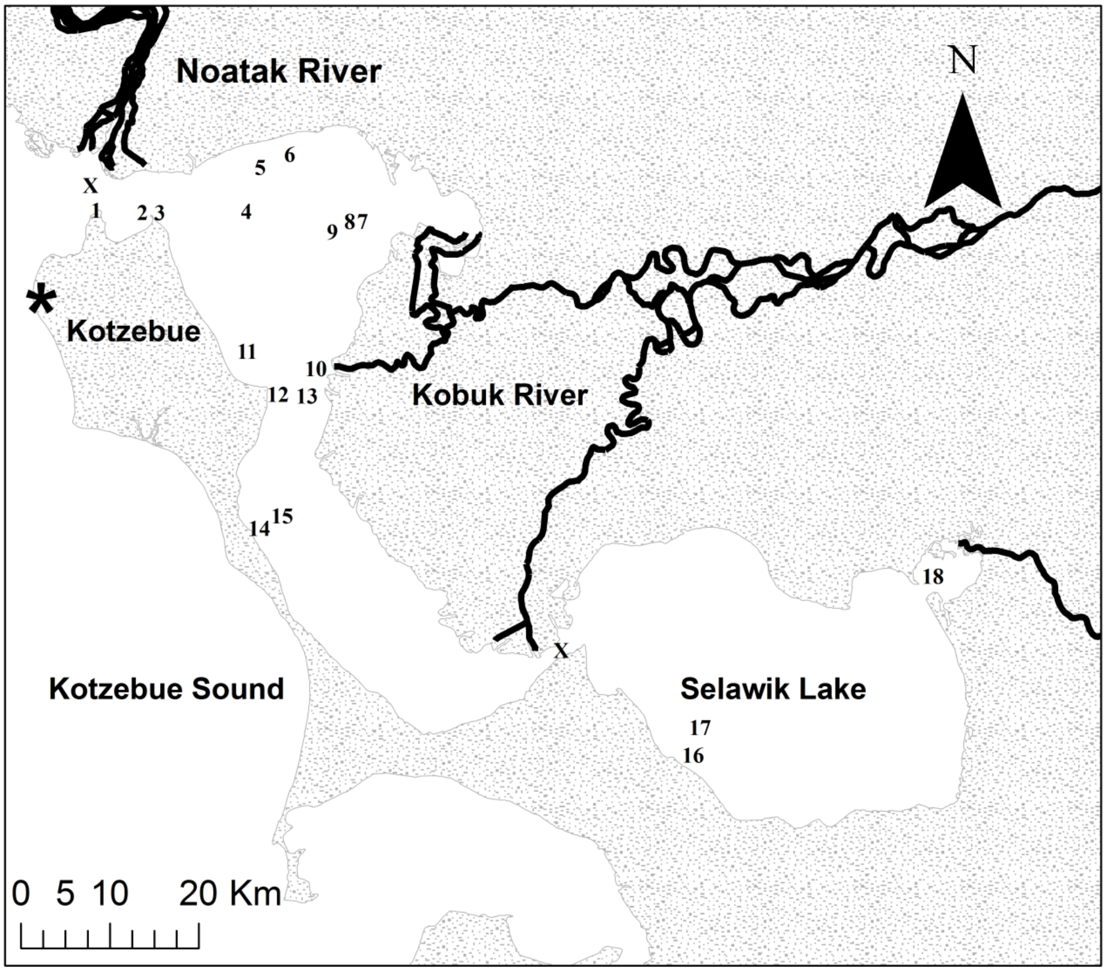


Figure 2.2. Map of Hotham Inlet and Selawik Lake depicting locations of receiving stations. The receiving stations are identified by number (n = 18), with unrecovered stations identified with the letter X (n = 2).

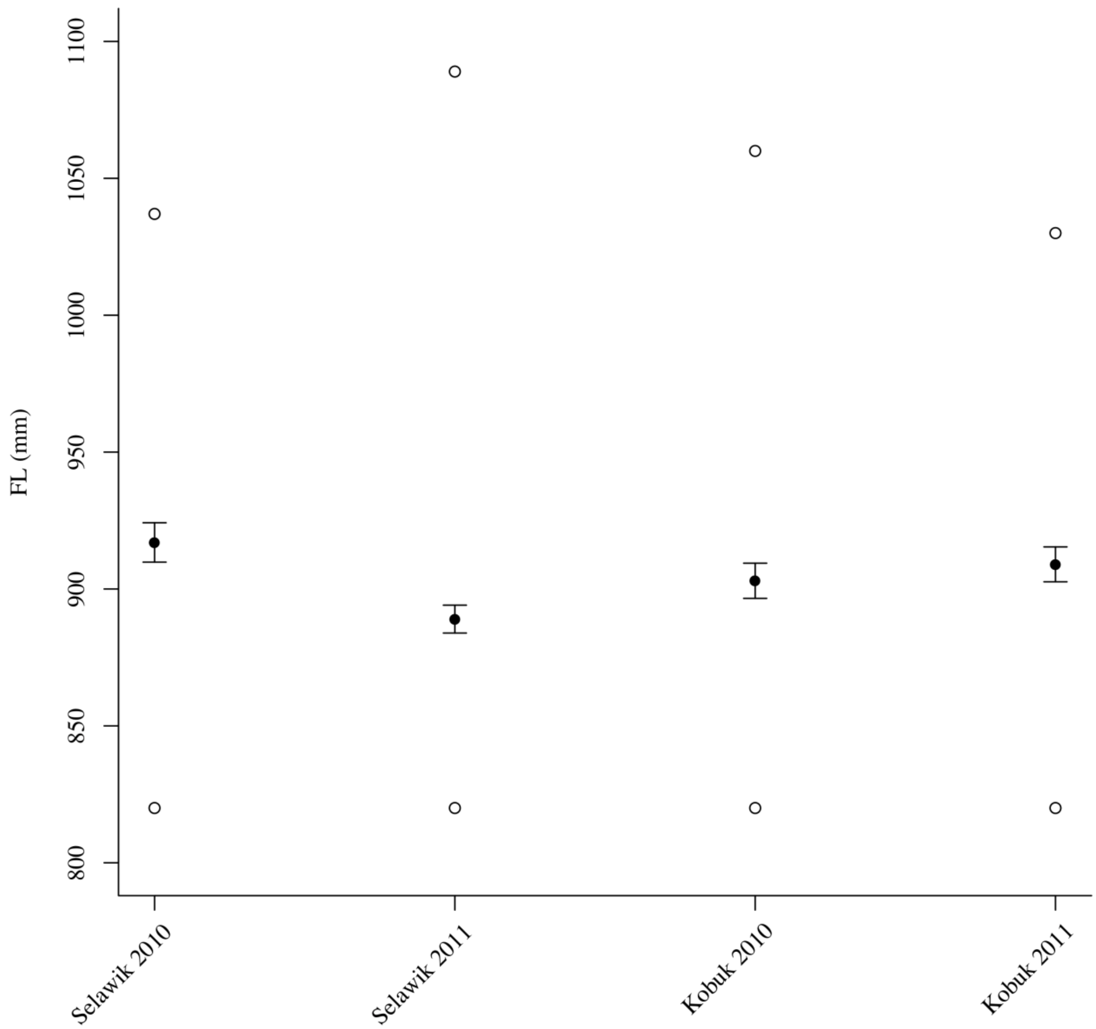


Figure 2.3. Mean fork length (± SE; solid circles) and range (hollow circles) for inconnu captured and tagged from the Selawik and Kobuk rivers in 2010 and 2011.

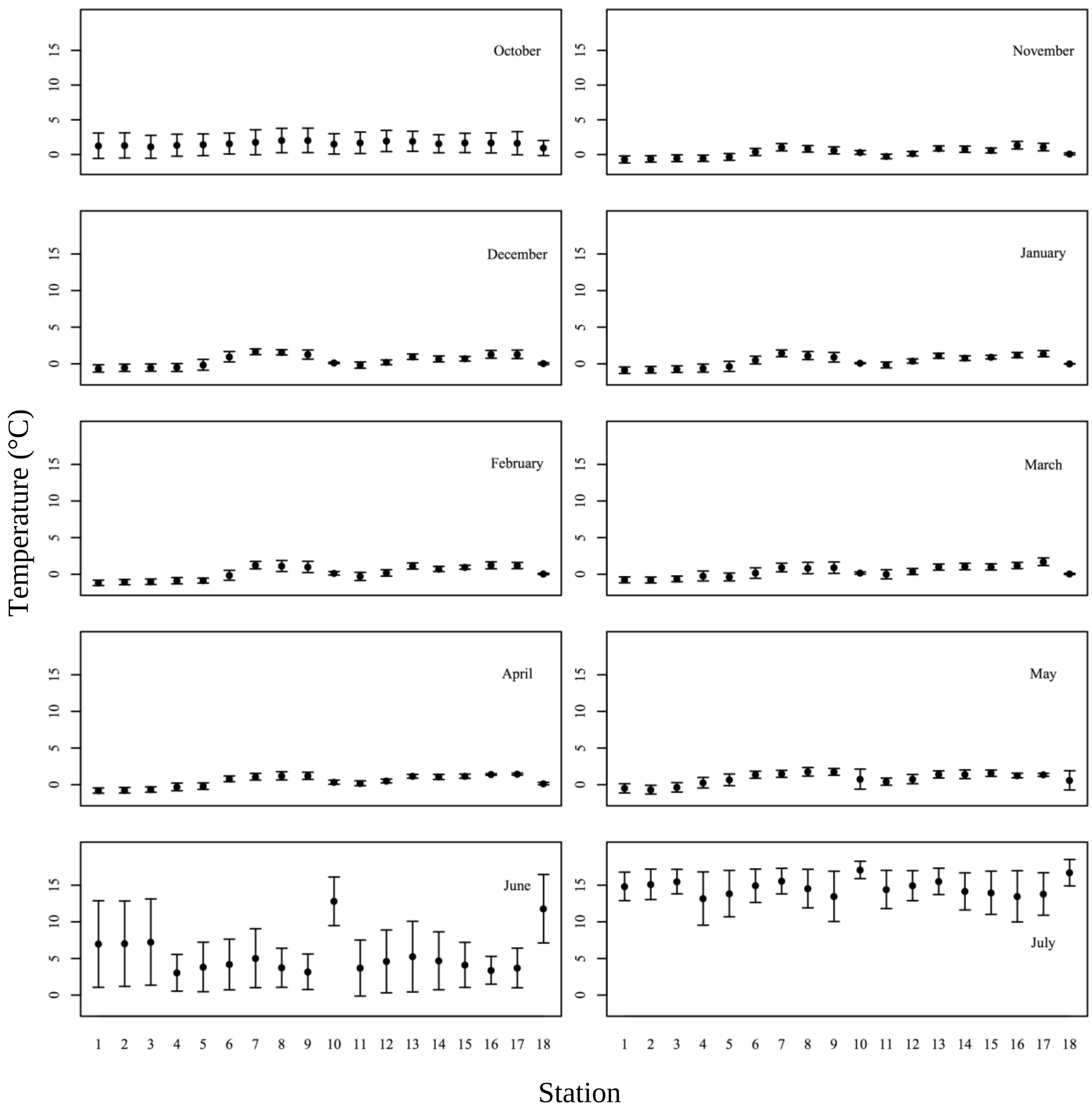


Figure 2.4. Mean (± SD) monthly water temperature for receiving stations (n = 18; see Figure 2.2 for locations). The receiving stations are arranged in a north (left) to south (right) orientation to depict spatial trends.

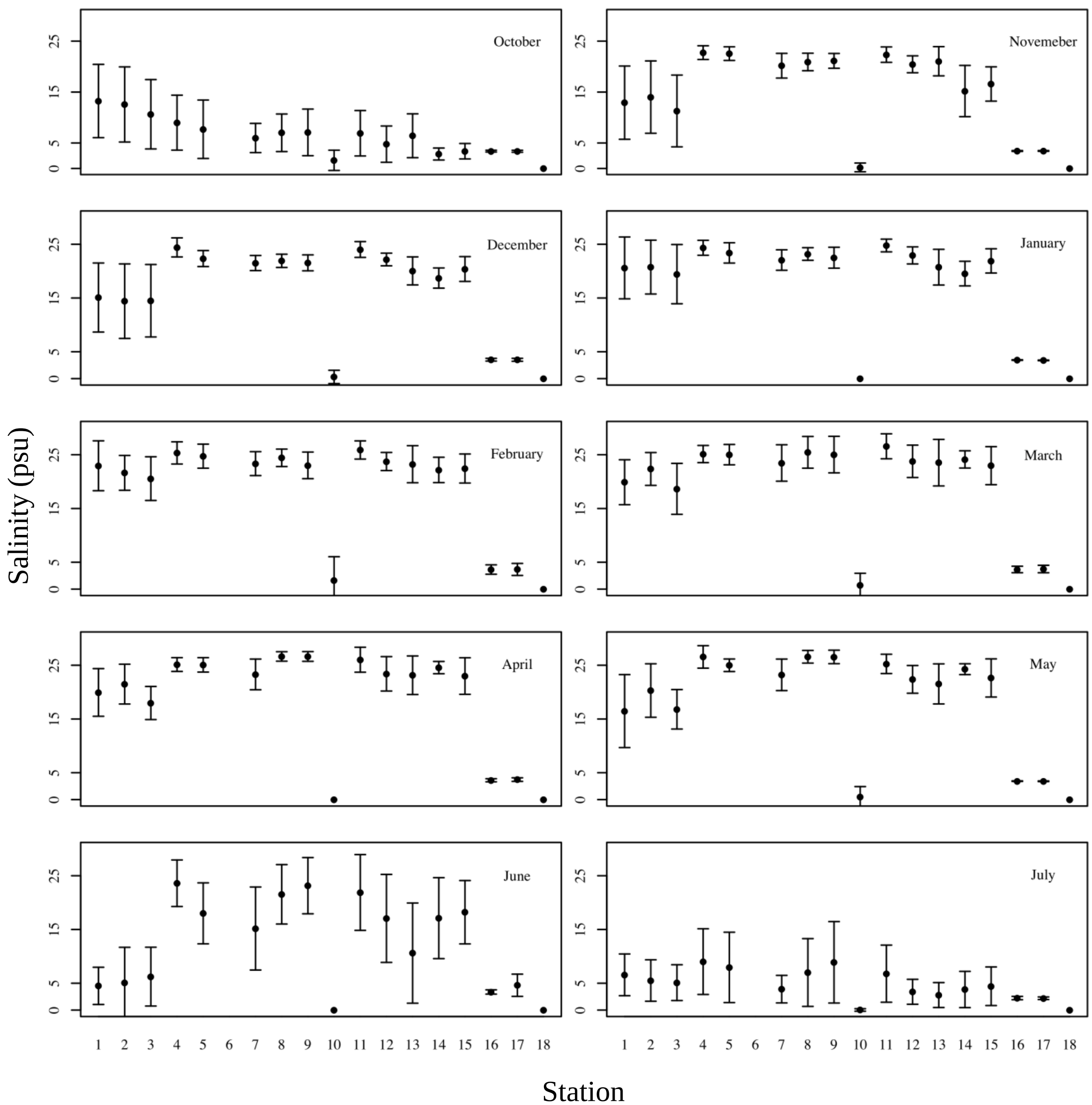


Figure 2.5. Mean (± SD) monthly salinity for receiving stations (n = 18; see Figure 2.2 for locations). The receiving stations are arranged in a north (left) to south (right) orientation to depict spatial trends.

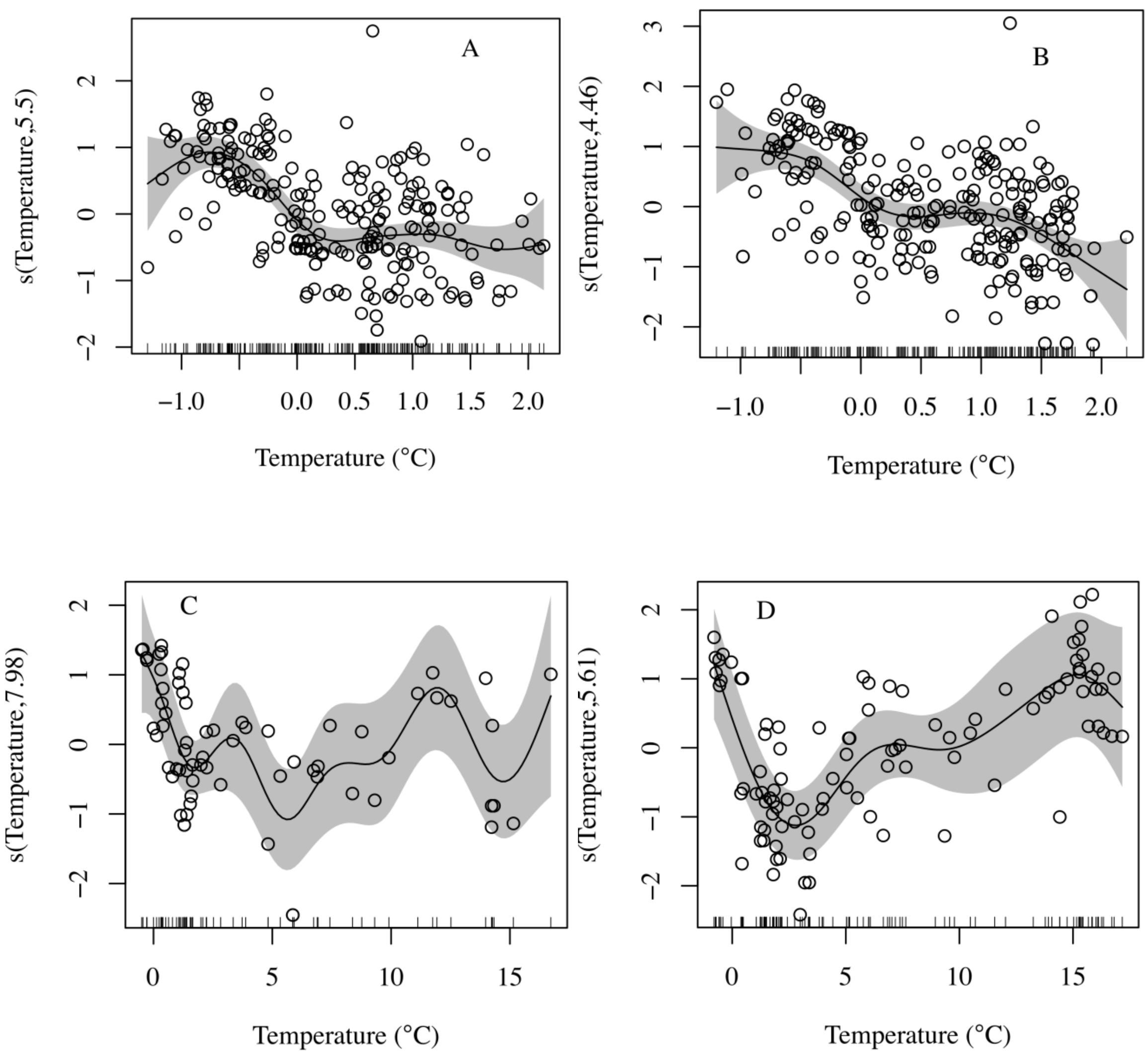


Figure 2.6. Generalized additive model (GAM) partial regression plots of winter (A) 2010-2011 and (B) 2011-2012 and summer (C) 2011 and (D) 2012 water temperature occupancy. The GAM trendline (solid line) is bounded by a 95% confidence interval (gray shaded area) and partial residuals. The y-axis represents the effect of the water temperature on habitat occupancy, where s is a smoother term and the number in parentheses is the equivalent degrees of freedom (edf). Ticks on the x-axis represent the observed water temperature values and aid in interpretation of the distribution of temperature occupancy.

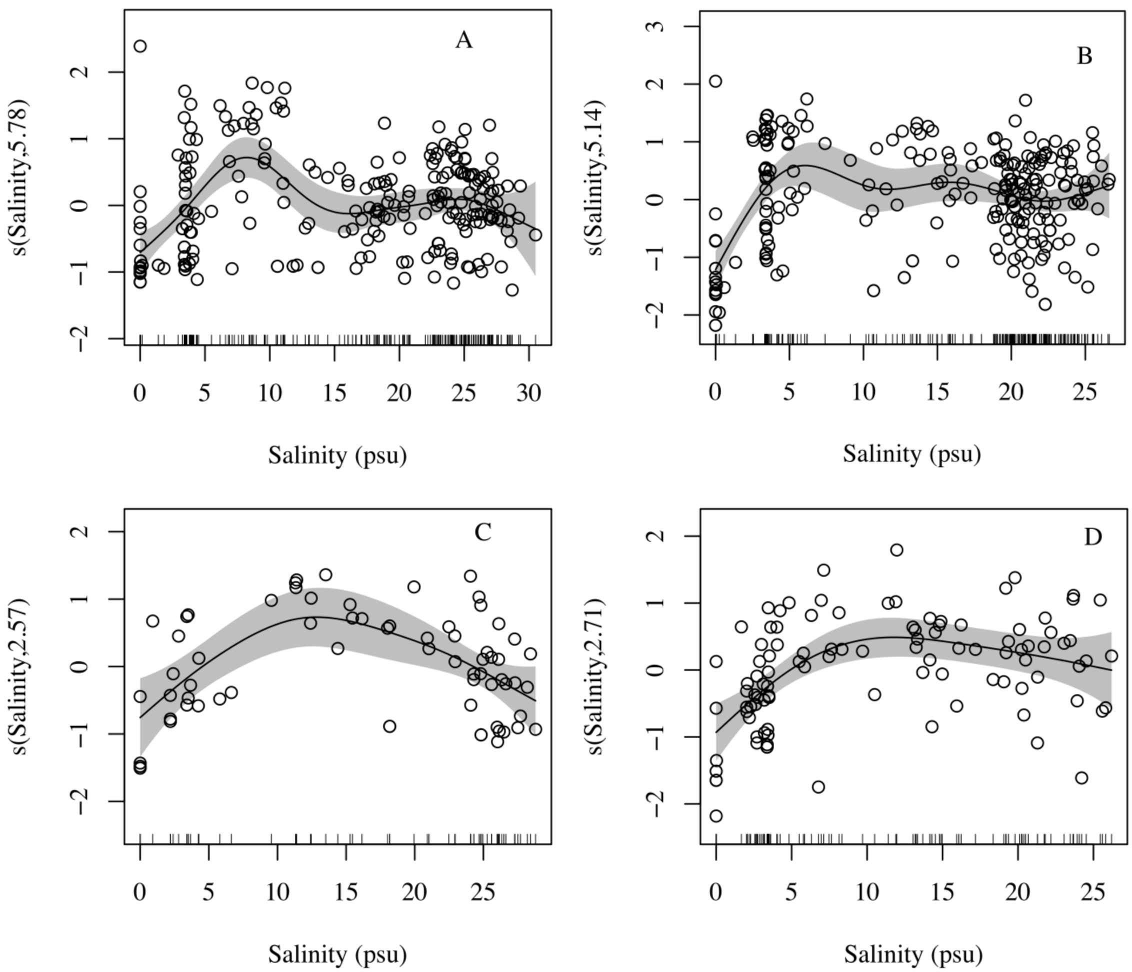


Figure 2.7. Generalized additive model (GAM) partial regression plots of winter (A) 2010-2011 and (B) 2011-2012 and summer (C) 2011 and (D) 2012 salinity occupancy. The GAM trendline (solid line) is bounded by a 95% confidence interval (gray shaded area) and partial residuals. The y-axis represents the effect of salinity on habitat occupancy, where s is a smoother term and the number in parentheses is the equivalent degrees of freedom (edf). Ticks on the x-axis represent the observed salinity values and aid in interpretation of the salinity occupancy distribution.

**Conclusions**

My study results increased our understanding of the movements and habitat occupancy of inconnu in the Kotzebue region. In chapter one, I described the movements of inconnu from the Selawik and Kobuk rivers while these fish were located within the Hotham Inlet/Selawik Lake Complex. During their seasonal movements, both populations of inconnu exhibited strong patterns of spatial and temporal overlap, with the greatest overlap occurring in the northern end of Hotham Inlet. The second chapter described the water temperatures and salinities occupied by each stock while being co-located in the Hotham Inlet/Selawik Lake complex. No stock-specific patterns of habitat occupancy were detected during my study, and individuals from both stocks occupied colder water temperatures during winter months. In contrast, water temperature occupancy over the summer periods was variable, with no visible trends observed. Inconnu occupied the entire range of salinities present during both summer and winter seasons, but had the lowest occupancy in the lowest salinities (0 to 5 psu). In addition to increasing our understanding of inconnu ecology, both chapters of my thesis added considerable evidence that these two populations are a completely mixed stock while located within the Hotham Inlet/Selawik Lake complex.

As an important subsistence resource in the Kotzebue region, it is imperative to understand the life-history characteristics of inconnu, which ultimately allows managers to accurately assess and make informed management decisions. Because winter subsistence harvest comprises the largest component of total harvest and inconnu in this region are a mixed stock, knowledge of movements and distribution will be critical for establishing science-based, stock-specific harvest guidelines for the winter fishery (Savereide 2002). However, without knowing the contribution to total winter subsistence harvest by each stock, the establishment of stock-specific harvest guidelines is not feasible. As a result, managers will need to set harvest quotas to maintain the sustainability of the smaller Selawik River stock if winter harvest restrictions are warranted. This approach has been successfully implemented in other Alaskan mixed-species fisheries. One example is the Chatanika River personal-use whitefish spear fishery located near Fairbanks, Alaska (Brase and Baker 2011). In the Chatanika River spear fishery, humpback whitefish *Coregonus pidschian* are the target species; however, least cisco *C. sardinella* are bycatch because both species co-occur both spatially and temporally during the harvest period, which parallels their spawning season. For this fishery, species-specific harvest guidelines are not feasible because fish cannot be identified by species prior to spear harvest. To manage the fishery, simulation models using species- and system-specific rate-dynamic parameters from humpback whitefish and least cisco were used to determine the level of total harvest that would allow for the sustainability of the less abundant least cisco stock (Edenfield 2009). If harvest restrictions are required for Kotzebue region inconnu, simulation models are a valuable tool that can be used to estimate sustainable winter harvest of the smaller Selawik River stock. Because the largest spatial overlap between inconnu from the Selawik and Kobuk rivers occurred on traditional subsistence fishing areas (Savereide 2002), managers could, if necessary, also implement specific harvest strategies such as area closures, set fishing seasons, and gill-net mesh/angling restrictions to reduce the risk of overharvest.

In addition to elucidating the feasibility of stock-specific winter harvest guidelines, my study results will be useful for determining future effects of anthropogenic- or climate-induced changes in the region. Specifically, the results of my study will serve as baseline information that future research can use to identify any changes in movement and distribution patterns of Kotzebue region inconnu. Although climate change will have an impact in the Arctic region, it is not possible to impose regulations or polices to reverse these environmental modifications. As a result, it is also prudent to have baseline data available to identify possible climate change effects in this region. Environmental results can also be compared to future collections to identify changes in water temperature and salinity characteristics within Hotham Inlet and Selawik Lake. From my study, it is also possible to identify the impacts to inconnu from human alterations, such as mineral exploration/extraction, hydrokinetic power generation, substrate dredging, etc. For example, if an industry-induced catastrophic event (e.g., oil-well blowout, chemical spill, etc…) was to occur in Hotham Inlet during the ice-covered period, the consequences to inconnu would be highly detrimental because this area contains the largest concentration of inconnu from both stocks. Therefore, prior to granting human landscape alterations or activities, a critical review of the potential detrimental effects on inconnu must be identified.

Currently, impacts on habitat quality and quantity by the production of ice roads poses a potential risk to inconnu in this region. In the shallower regions of the study area (e.g., transition from Selawik Lake to Hotham Inlet), water drawdown could possibly lower the depth of water around the pumping station enough to create barriers to fish passage. Additionally, with the saline waters of Hotham Inlet and Selawik Lake becoming stratified during the winter period, it is possible that water drawdowns would remove the fresh water lens and replace it with a vertical column of highly saline waters. This vertical column may create a barrier to movement, which could also limit access to core winter areas. Aside from the ice road that extends into the SNWR, there is an ice road that transects Hotham Inlet and connects Kotzebue to communities on the Kobuk River. However, this ice road does not rely on water drawdowns for construction, and therefore poses no direct threat to inconnu (G. Skin, Northwest Arctic Borough Public Services Department, personal communication). From my movement and habitat results, the ice road that extends between the native village of Selawik and an inholding with the SNWR boundary also poses little to no risk to overwintering adult inconnu because these fish do not occur near the Native Village of Selawik during this period. Because, inconnu from both stocks overwinter in the northern end of Hotham Inlet, ice roads that require water drawdowns should be avoided in this area to mitigate any unforeseen effects on inconnu.

Although my study has provided a better understanding of the movement patterns and habitat requirements of adult Kotzebue region inconnu located in summer feeding and overwintering areas, many questions still remain about the biology of inconnu. Currently, the largest gap in knowledge lies with juvenile inconnu ecology. Do juvenile inconnu exhibit the same movement patterns as adult inconnu that reside in Hotham Inlet and Selawik Lake? What are the habitat requirements of juvenile inconnu, and how will anthropogenic- and climate-induced changes affect their growth and survival? These questions represent a few areas that should be considered for future research. Given the importance of inconnu as a subsistence resource in this region of Alaska, expanding our understanding of Kotzebue region inconnu will allow for the continued and sustainable harvest in the future.

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Savereide, J. W. 2002. Under-ice gillnet harvest of sheefish in Hotham inlet in 2000-2001. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series Number 02-04, Anchorage.

# Appendix A
# IACUC Approval

UAF
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**Institutional Animal Care and Use Committee**
909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

June 25, 2010

| | |
|---|---|
| To: | Trent Sutton, B.S., M.S., Ph.D.<br>Principal Investigator |
| From: | University of Alaska Fairbanks IACUC |
| Re: | [154481-3] Winter Movement Patterns and Habitat Use of Selawik Drainage Inconnu |

The IACUC reviewed and approved the Amendment/Modification referenced below by Designated Member Review.

| | |
|---|---|
| Received: | June 18, 2010 |
| Approval Date: | June 25, 2010 |
| Initial Approval Date: | April 6, 2010 |
| Expiration Date: | April 6, 2011 |

This action is included on the July 1, 2010 IACUC Agenda.

*The PI is responsible for acquiring and maintaining all necessary permits and permissions prior to beginning work on this protocol. Failure to obtain or maintain valid permits is considered a violation of an IACUC protocol, and could result in revocation of IACUC approval.*

# Appendix B
## Summary of data from two previously at large receiving stations

On July 19, 2013, two UAF scientific divers successfully retrieved the two receiving stations that remained in the study area following the completion of this research project. These two receiving stations were located at the mouth of the Noatak River and at the Selawik Lake-Hotham Inlet junction (Figure 1.2). The divers reported that the receiving stations had become buried by sediment to the top of the crab-pot floats. As a result, these receiving stations could not be retrieved with the grappling hook during the two previous recovery attempts in 2011 and 2012.

The two receiving stations yielded 9,509 and 5,859 detections from 77 and 72 unique fish from the Selawik and Kobuk rivers, respectively. Of the unique inconnu that were detected by these receiving stations, 80 fish were tagged in summer 2010 and 69 fish were tagged in summer 2011. In addition, five Kobuk River inconnu that had not been previously detected at the other 18 receiving stations were detected at the receiving station located at the Selawik Lake-Hotham Inlet junction. Detection records showed that the receiving stations did not detect any tagged inconnu after July 2012, approximately 23 months post-deployment, due to battery exhaustion.

Inconnu detections recorded at the 18 receiving station that were retrieved in 2011 and 2012 showed that the seasonal movements and distributions of Kotzebue region inconnu followed a consistent pattern. Upon entering the Hotham Inlet/Selawik Lake in late September and early October, tagged fish occupied the northern end of Hotham Inlet during the winter period. Fish from both rivers were detected moving to Selawik Lake periodically throughout the winter period. During summer, fish transitioned from the northern end of Hotham Inlet to Selawik Lake and the southern end of Hotham Inlet. Results from the two receiving stations retrieved in 2013 revealed that the movements and distributions of inconnu from both river stocks corroborated the aforementioned movement and distribution patterns. Initial inconnu detections occurred at the receiving station located at the Selawik Lake-Hotham Inlet junction on September 18, 2010, ten days earlier than described previously. Incorporating these data with information from the 18 receiving stations that were retrieved in 2011 and 2012 enhanced the description of the seasonal movement patterns of Kotzebue region inconnu. Fish from Selawik and Kobuk river stocks were detected at the Selawik Lake-Hotham Inlet junction station until mid-November 2010 and 2011, which was consistent with data from nearby receiving stations. As winter progressed, inconnu moved into the northern end of Hotham Inlet, with fish detected at the Noatak River mouth station. After May 2011 and 2012, when fish transitioned back to the southern end of Hotham Inlet and Selawik Lake, inconnu detections were recorded at the Selawik Lake-Hotham Inlet juncture.

Based on detections at the 18 receiving stations retrieved in 2011 and 2012, inconnu from the Kobuk and Selawik rivers occupied water temperatures ranging from -1.39 to 18.69ºC. Detections at the Noatak River mouth receiving station identified that inconnu occupied water temperatures ranging from -1.08 to 23.51°C. Water temperature occupancy at the Selawik Lake-Hotham Inlet junction ranged from -0.29 to 12.60°C. Data from these two receiving stations indicated that inconnu occupy warmer water temperatures than previously recorded. Comparisons of seasonal trends in water temperature occupancy from the two recently retrieved receiving stations mirrored that of the water temperature occupancy from the 18 receiving station that were retrieved in 2011 and 2012.

The addition of inconnu detections from the two receiving stations retrieved in 2013 has added to our understanding of the movement patterns and habitat occupancy of inconnu from the Kobuk and Selawik rivers. Specifically, these data corroborated the results previously described in my thesis from the 18 receiving stations retrieved in 2011 and 2012. As a result, the information from the two additional receiving stations strengthens the description of the seasonal movement patterns and habitat occupancy of Kotzebue region inconnu.